Decoding farm size-performance relationship in Algerian agriculture: Toward a unified analytical framework

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Abstract

The relationship between farm size and performance remains a central but contested issue in agricultural economics. While existing studies tend to classify this relationship (positive, inverse, or neutral), they rarely explore the underlying mechanisms, leading to context-dependent findings. This study addresses this gap by analyzing three agricultural value chains in Algeria – artichoke, honey, and tomato – using a comparative, mixed-methods approach. It identifies "structural differentiation levers", internal or external factors rooted in specific spatiotemporal contexts, that indirectly affect performance via techno-organizational practices and economic mediators. In the artichoke chain, these levers relate to access to water and market structures favoring large farms. In the honey chain, they reflect sanitary, organizational, and commercial conditions benefiting small-scale producers. In the tomato chain, their absence explains the performance parity across farm sizes. The analysis shows that size-related advantages arise only when three conditions are met: favorable levers, a size suited to them, and the farmer's capacity to activate them.

Keywords: *Farm size, Performance, Structural differentiation levers, Agricultural value chains, Algeria.*

1. Introduction

The relationship between farm size and performance lies at the heart of debates on the efficiency, sustainability, and equity of global agricultural systems, including those in the Maghreb and broader Mediterranean regions, where land scarcity, informality, and fragmented farm structures are critical issues. These systems face increasing pressure to produce more with limited resources while addressing goals related to food security, employment creation, wealth generation, and ecosystem preservation (Eastwood *et al*., 2010). More broadly, these debates revolve around identifying the most effective productive configurations – whether based on land, livestock, or other structuring factors. Farm performance is closely linked to the techno-organizational model adopted, which is itself influenced by the size of the production unit. In this context, determining whether small or large farms are more efficient is crucial to inform agricultural policy. Research on the relationship between farm size and performance (whether measured in physical or value terms), which has seen renewed interest in recent years, is anchored in this fundamental question. These studies employ diverse methodologies and yield mixed results,

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leading to the identification of a typology of relationships (Deininger and Byerlee, 2012).

On one hand, some studies highlight a positive relationship between size and performance, emphasizing the advantages of larger farms. These include economies of scale, better access to modern technologies, and greater integration into global value chains. For instance, Adamopoulos and Restuccia (2014) demonstrated that in developed countries, large farms benefit from access to advanced technologies that boost productivity, a challenge also faced by Mediterranean regions seeking to modernize smallholder agriculture. Similarly, Yao and Hamori (2019), using aggregate data from 29 Chinese provinces, observed a long-term positive relationship and recommended expanding large farms to support agricultural development, a policy trend that echoes land consolidation debates in North Africa, particularly in the last decade. Similar observations have been made in developing countries, as in Muyanga and Jayne's (2019) study in Kenya, which is particularly relevant for countries with dualistic farm structures like Algeria. Assassi (2023) identified a positive relationship in Algeria's canning tomato sector, where larger producers leverage economies of scale through personal means of transport use and mechanized planting and harvesting operations.

On the other hand, a significant body of research supports an inverse relationship, where smaller farms outperform larger ones. These studies argue that small farms primarily rely on family labor, optimizing resource allocation. Fan and Chan-Kang (2005) found that in China, small farms outperformed large ones due to intensive land management and efficient labor allocation, a situation that mirrors many smallholder farming contexts in the Maghreb. Studies such as those by Deininger and Jin (2003) in Vietnam, Ansoms and Van Ranst (2008) in Rwanda, and Barrett et al. (2010) in Madagascar corroborate this conclusion by highlighting superior resource management in small farms. Blackmore et al. (2018) indicates their ability to diversify their production system and the positive impact of this approach on their income, which is particularly relevant in diversified agrosystems of Mediterranean oases and peri-urban zones. Temporal data also reinforce this finding but point to the weakening of the inverse relationship due to capital replacing labor, as shown by Deininger *et al*. (2018) in India, a trend that resonates with the increasing mechanization observed in North African horticulture.

In parallel, other studies reveal complex, non-linear or null relationships. Savastano and Scandizzo (2017), for example, described a "direct-inverse-direct" dynamic in sub-Saharan Africa, influenced by factors such as public policies and infrastructure, elements that strongly shape farm performance in Algeria as well. Across multiple case studies from different continents, Rada and Fuglie (2019) demonstrated that agricultural mechanization tends to attenuate the inverse relationship between size and productivity, highlighting the impact of modernization and rising wages, both relevant to ongoing transformations in Maghrebian labor markets. Sheng *et al*. (2019) identified a U-shaped relationship in China, explained by inefficient input use. Finally, Benmehaia (2022) observed an almost absent relationship in greenhouse vegetable farms in Biskra, southeast Algeria.

A fourth category includes general studies that find no universal patterns. For instance, Eastwood *et al*. (2010) concluded that results vary based on factors such as infrastructure and agricultural policies, underlining the importance of context-sensitive analysis in regions like the Maghreb. Colin and Bouquet (2022) argued that the relative performance of farms depends on numerous, often localized factors. Other studies, such as Carletto et al. (2013), highlighted methodological biases influencing perceptions of this relationship.

Despite the wealth of existing research on the size-performance relationship, the literature primarily focuses on characterizing the type of relationship (positive, inverse, complex) and identifying the technical and organizational factors that shape it. These studies underscore the diversity of results, suggesting that this relationship varies according to local contexts and agricultural specificities. However, a fundamental question remains unexplored: are the underlying mechanisms – i.e., the operational processes – of this relationship themselves diversified, or do they follow a systematic logic? Addressing this question could reveal whether it is possible to develop a unified framework for understanding the size-performance dynamic or whether each situation indeed requires a distinct contextual approach. This article addresses this novel issue, seeking to clarify whether contextual specificities can be transcended to construct a universal analytical methodology.

To answer this question, we selected three distinct agricultural value chains in Algeria: artichokes in Oued Rhiou (wilaya – province – of Relizane), honey in eastern Algiers, and greenhouse tomatoes in El Ghrous (wilaya of Biskra). These case studies allow for a comparison of varying relationships (positive, inverse, and null) between farm size and performance. An in-depth analysis of the underlying mechanisms is conducted for each value chain, considering structural factors, agricultural practices, and market contexts.

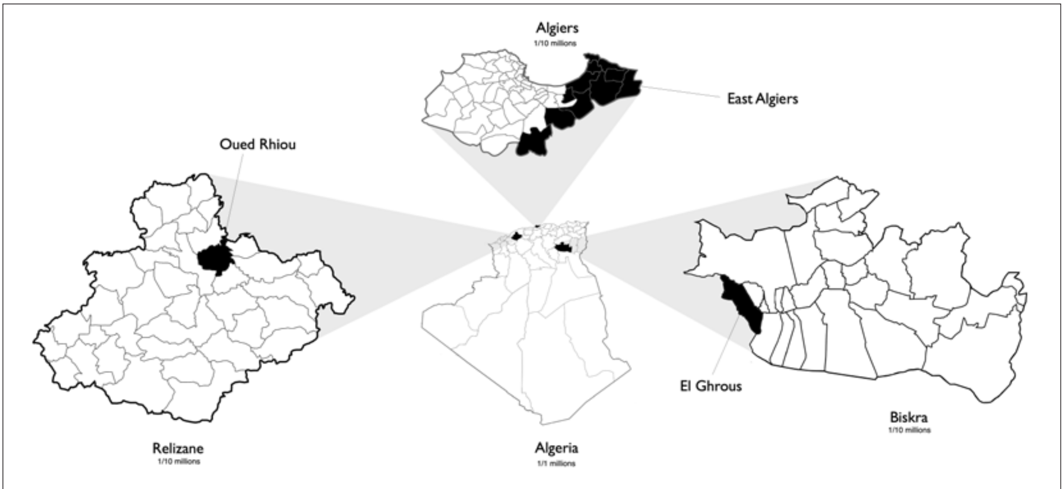
The article is structured into five main sections. The context section details the rationale for the selected case studies. The methodology section outlines the approach adopted. The results section presents the mechanisms observed in each sector. The discussion explores whether a systematic logic emerges or whether contextual specificities prevail. Finally, the conclusion summarizes the key findings and their implications for research and policy.

2. Context

This study examines three agricultural value chains located in distinct regions: artichoke in Oued Rhiou (Relizane province, 300 km west of Algiers), honey in East Algiers (across eight highly productive municipalities), and greenhouse tomato in El Ghrous (Biskra province, 400 km southeast of Algiers) (Figure 1).

In 2022, Oued Rhiou, a region known for cereals, citrus, and vegetables, dedicated 520 hectares to artichokes, cultivated by 87 producers (average farm size 5.9 ha), with a total output of 95,680 quintals (10% of national artichoke area – Relizane Agricultural Services Directorate, 2022). These lands, primarily state-owned, are operated under long-term usage rights granted to private concessionaires. Artichoke cultivation is centered in two irrigated perimeters, Bas-Chéliff and Mina, which face water shortages in July, crucial for crop maturation. Farmers with boreholes mix perimeter water with groundwater, though borehole use is restricted to large plots to protect the aquifer. Some producers use their own lands (including state-allocated), while others rely on informal seasonal rentals, accessing perimeter and borehole water when available. Tenants pay rental and water costs; plots are rented whole without subdivision. Boreholes are managed individually, with no water market. Harvesting, done approximately in three rounds, requires an important seasonal la-

Figure 1 - Map showing the location of the three study areas.



bor. Marketing is constrained by the absence of a local wholesale market: most sell at informal “stock exchanges” in Oued Rhiou and Djdiioua, in cafeterias where brokers set daily prices (from 120 DZD/kg in November to 10 DZD/kg in April 2022) based on quantity and quality, especially bract closure. Producers delegate negotiations to brokers, who receive per-kilogram commissions. Sales occur at farms, handled by producers with available labor or by wholesalers, who may charge for harvesting and transport.

East Algiers covers 10,277 hectares (9,212 hectares of usable agricultural area), dominated by arboriculture and vegetables. In 2023, it hosted 80 beekeepers managing 3,469 hives, producing 15,088 kg of honey. Production depends on self-financed beekeepers lacking credit access. Hives are placed in local orchards, forests, and melliferous zones of nearby provinces (Ouakli *et al*., 2019). Operations vary from sedentary to transhumant, seeking diverse melliferous resources. Productivity is enhanced by techniques like artificial swarming. Beekeepers fall into two groups: professionals combining beekeeping with farming, and amateurs with other jobs who value its flexibility and low labor demand (Neggache, 2018). Few belong to professional organizations, limiting collective structuring. Marketing involves a dominant short circuit of direct sales at local markets and a secondary circuit via wholesalers and retailers.

El Ghrous (Biskra province), also known for dates, is a key center for early-season greenhouse tomatoes. Production is driven by non-local farmers attracted by the land market, groundwater availability, and sunny climate. Land is leased per greenhouse unit, usually including water from private boreholes (with shared-use agreements), typically for three years with cash-paid, upfront seasonal rent (Daoudi *et al*., 2017). In 2023, 115 greenhouse farmers operated in the area; 90 grew tomatoes along with zucchini and peppers (Assassi et al., forthcoming). Highly perishable, tomatoes are marketed without storage through El Ghrous’s wholesale market, where farmers sell directly alongside wholesalers from across Algeria. These wholesalers distribute rapidly to urban semi-wholesale markets, then to retailers, ensuring same-day delivery of fresh produce to consumers (Assassi *et al*., 2017).

3. Data and methodology

3.1. *Methodology*

This study examines whether the relationship between farm size and performance follows a systematic logic or depends on specific contextual factors. We adopt a bottom-up approach to detect causal effects, analyze underlying mechanisms, and identify structural levers influencing this dynamic across various spatio-temporal contexts. Three agricultural sectors were analyzed: artichoke farming in Oued Rhiou (Relizane), honey production in the East Algiers, and greenhouse-grown early-season tomatoes in El Ghrous (Biskra). These cases, selected based on their respective size-performance relationships (positive, inverted, and null) enable us to explore whether a systematic logic underpins these dynamics or if each sector follows a logic inherent to its specific characteristics.

Initially, Student’s t-tests were employed to compare the performance of small and large farms across the three value chains. No control variables other than size were included to capture all potential differences. Performance was measured by net profit per unit of the principal factor for a complete campaign. Net profit refers to the difference between total revenues (calculated as selling price multiplied by quantity sold) and total production costs over a complete campaign, representing the farm’s actual financial gain. Net profit was chosen as the analytical indicator for its ability to reflect all productive and financial differences. The main factor unit was used as a control element since it best represents farm size, and consequently the technical model adopted: land area for artichokes, number of hives for honey, and number of greenhouses for tomatoes. Consequently, performance indicators were net profit per hectare, per hive, and per greenhouse, respectively. The choice of a complete campaign lies in its ability to capture the full scope of production over an entire cycle, reflecting the seasonal variations in costs, yields, and revenues that can influence profitability.

We identified the determinants of net profit by analyzing performance mediators (cost, yield, sale price) to explain the observed differences between small and large farms. This analysis was conducted using Student's t-tests to compare these mediators across the two farm types. To calculate the cost per main factor unit (C_{imfu}), we calculated the total cost (C_{iT}) of each farm and divided it by its size (S_{iT}) – total costs include all expenses actually incurred over a complete production cycle of the activity, including input costs, access to natural resources, energy, services, equipment depreciation, marketing, and labor costs; the latter corresponds to wages effectively paid to hired workers or to family labor, valued at zero when unpaid :

$$C_{imfu} = \frac{C_{iT}}{S_{iT}} \quad (1)$$

Once key mediators were identified, we explored the techno-organizational determinants (inputs, production and commercial practices) responsible for these differences, again using Student's t-tests.

To detect techno-organizational differences attributable to farm size, we conducted linear regressions (Equation 2). Each techno-organizational factor (dependent variable) was related to farm size (independent variable). These analyses were restricted to value chains where significant net profit differences were observed, namely artichoke farming and honey production.

$$Y_{it} = B_0 + B_1 \, x \, Size_{it} + \varepsilon_{it} \quad (2)$$

Where:
Y_{it}: Dependent variable representing the techno-organizational factor for farm *i* in value chain *t*.
$Size_{it}$: Independent variable representing the size of farm *i* in value chain *t*.
B_0 : Constant, representing the regression intercept.
B_1 : Coefficient associated with farm size, indicating its effect on the dependent variable.
ε_{it} : Error term.

To address endogeneity biases in the analysis between size and techno-organizational factors, an adjusted size variable was created for each value chain. This variable was derived from a linear regression using instrumental variables strongly correlated with size but independent of net profit and performance mediators. Instrumental variables were selected after qualitative analysis and correlation tests. In the artichoke sector, the chosen instrumental variables were total land area owned and the number of tractors, reflecting the capacity to cultivate irrigated areas. For honey production, variables such as the age and experience of the farmer and engagement in complementary activities were chosen, as these factors influence hive management. The resulting linear regressions corrected biases by assigning the adjusted size variable an independent role, enabling a more precise and reliable analysis of farm size effects on performance.

Causal relationships between farm size and organizational determinants, highlighted by linear regressions, were corroborated through qualitative analyses. These analyses relied on targeted interviews with farmers, elucidating the underlying mechanisms driving the observed differences and providing contextual validation for the quantitative results.

3.2. *Sampling and data collection*

The adopted methodology relies on primary and secondary data collected for the three value chains studied. The value chains were selected following an exploratory survey conducted in consultation with the National Chamber of Agriculture, which guided the initial choice. After validation through exploratory investigations, certain options were excluded; the canning tomato value chain in Guelma and the citrus value chain in Blida were deemed unsuitable and were replaced respectively by early-season tomatoes from El Ghrous and honey from East Algiers, which were better aligned with the study's objectives.

Secondary data, provided by the Ministry of Agriculture and the agricultural directorates of the concerned wilayas, allowed for contextualization of the territories and value chains through information on farms, cultivated areas, and geographic distribution.

Primary data targeted agricultural farms, covering their structure (area, number of hives or greenhouses, equipment), the farmers (age, training, labor force), their operations (financing, land access, farming practices, marketing), and their performance (costs, yields, selling prices).

This information was collected through surveys of 90 farmers (30 per value chain), with each sample including 15 small and 15 large farmers selected randomly. Excluding medium-sized farms simplifies the analysis and allows for capturing clear contrasts in production models and performance, as these farms often mix practices from both extremes. This represents 50% of small-scale and 88% of large-scale artichoke producers in Oued Rhiou, 63% of small and 94% of large honey producers in East Algiers, and 50% of small and 83% of large tomato producers in El Ghrous.

Given that farm size is used as a control variable in this study (as in all similar studies) to reflect the technical model adopted, we have established thresholds based on technical criteria identified during exploratory surveys to classify the surveyed farms. Accordingly, we define a small farm as one that can be managed by a single individual without requiring sophisticated equipment, while a large farm is characterized by the need for hired labor or reliance on advanced equipment:

- Artichoke: Large farmers (≥8 ha), small farmers (≤3 ha).
- Honey: Large farmers (≥100 hives), small farmers (≤20 hives).
- Tomatoes: Large farmers (≥20 greenhouses), small farmers (≤5 greenhouses).

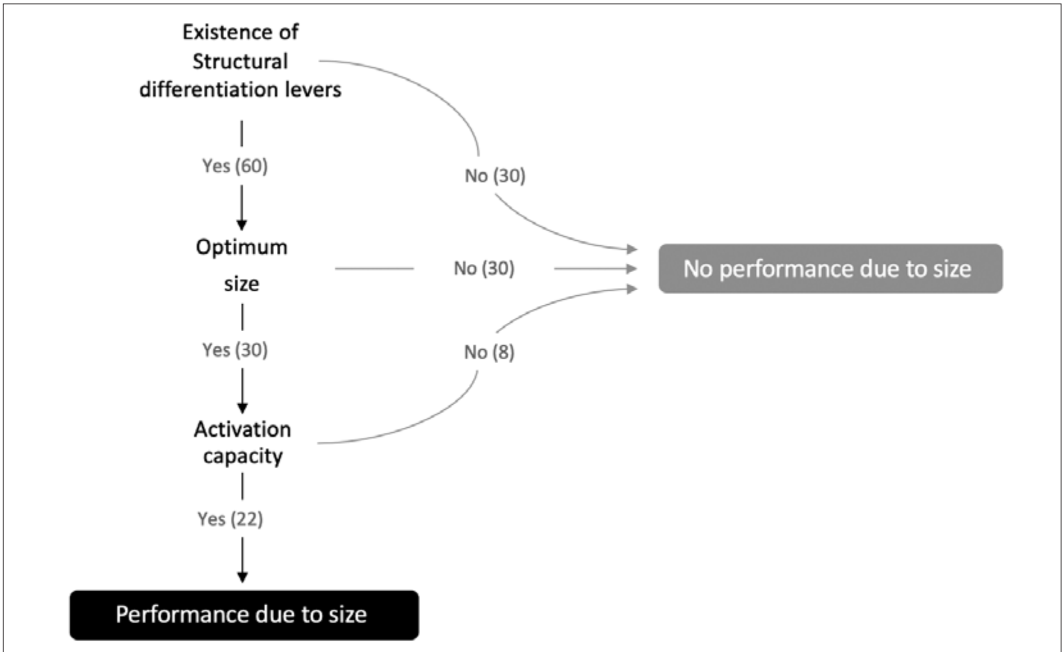
Considering that beekeeping is practiced recreationally by a large number of citizens in the study area, we chose to survey only professional beekeepers, those integrated into the market (who sell their products).

The data for artichokes and tomatoes pertain to the 2022 farming season, while the data for honey pertains to the 2023 season.

4. Results

The relationship between farm size and performance follows a systematic logic, regardless of its nature. It depends on the presence and the nature of factors that we refer to as "*structural differentiation levers*". These levers, whether internal or external to the farm, are specific to a spatio-temporal context and influence performance without being directly controllable by the farmers. They can be either permanent or temporary. When present, these levers favors a certain

Figure 2 - Conditional process of achieving size-related performance.



farm size by influencing techno-organizational practices (technical pathways or commercial strategies). These practices, in turn, affect performance mediators such as costs, yields, and prices, thereby impacting profits. In their absence, the relationship between size and performance tends to neutralize.

As shown in Figure 2, for a farm to gain economic advantages from its size, three conditions must be met: (1) the presence of favorable differentiation levers in its context, (2) the possession of an optimal size suited to these levers, in other words, a farm size that allows producers to benefit from structural advantages in the context, regardless of their strategy or intention, and (3) the ability of the concerned farms to activate these levers, which depends on certain "baseline conditions" such as the availability of resources and access to complementary infrastructures. These must accompany the condition of optimal size. Thus, even with an optimal size in a favorable context, potential gains remain contingent upon the farm's capacity to mobilize the necessary resources. In the absence of these conditions, the expected advantages linked to optimal size may fail to materialize, thereby limiting performance in an otherwise favorable environment. These aspects will be elaborated in the following sections.

4.1. *Characterization of small and large producers in the three value chains*

Table 1 highlights several similarities between small and large artichoke producers, particularly regarding the age of household heads, indicating generational consistency in this activity. Ownership of transport means is also comparable, reflecting similar mobility conditions. Larger farms, however, exhibit more frequent access to rented land and a stronger tendency towards polyculture. Differences in pluriactivity, tractor ownership, and the number of family members involved in farming are not statistically significant.

In the honey value chain, there are no significant differences between groups in the average number of years of education, practice of other agricultural activities, or the adoption of modern beehives. Larger farms, however, have significantly greater experience in honey production, an almost universal practice of transhumance, and greater use of specialized equipment, signaling higher levels of professionalization and agricultural intensification. The significantly older household heads in larger farms may suggest a correlation between accumulated experience and the capacity to develop larger-scale operations. While pluriactivity is marginally more frequent in smaller farms, the difference is not statistically significant.

In the tomato value chain, both groups share similarities in the age of household heads and levels of education. Neither engages in pluriactivity or owns tractors, indicating similar limitations regarding heavy agricultural equipment. However, larger farms exhibit higher ownership of transport means and a stronger tendency towards polyculture. They also involve more family members in farming, potentially reflecting intensified familial efforts to sustain larger operations. Access to leased land, though slightly more common among larger farms, is a widespread practice in both groups, emphasizing its relevance in this value chain.

4.2. *Comparison of the performance of small and large producers in the three value chains*

The performance comparisons between small and large producers in the three value chains validate the rationale for selecting them as case studies. As shown in Figure 3, the relationship between size and performance is positive in the artichoke value chain, reversed in the honey value chain, and neutral in the tomato value chain.

As illustrated Table 2 of Student's t-test, large artichoke producers achieve 114% higher net profit per hectare compared to small producers, owing to yields and selling prices that are 20% and 16% higher, respectively. Conversely, in the honey value chain, small producers obtain the highest profit per hive, with gains 27% higher than those of large producers. This is explained by selling prices that are 21% higher and production costs that are 34% lower. No difference was observed between small and large tomato producers, as performance mediators (costs, yields, and prices) were similar in both groups.

Table 1 - Comparison of characteristics of small and large producers in the three value chains.

	Variables	*Large farmers*	*Small farmers*	*Difference*	*p-value*
Artichoke	*Household characteristics*				
	Age of head of household (years)	45.8	46	-0.13	0.97
	Number of family workers	1	0.27	0.73	0.41
	Multiactivity (dummy)	0.13	0	0.13	0.46
	Multicrop (dummy)	0.47	0.93	-0.47	0***
	Number of years studied	7.93	7.60	0.33	0.86
	Agricultural training (dummy)	0.01	0	0	-
	Farm characteristics				
	Area under artichoke (hectare)	14	2.35	11.65	0***
	Access to land by renting (dummy)	0.53	0.27	0.26	0.26
	Possession of means of transport (dummy)	0.27	0.27	0	1.00
	Ownership of a tractor (dummy)	0.80	0.60	0.20	0.42
Honey	*Household characteristics*				
	Age of head of household (years)	52.1	43.34	8.73	0.07*
	Number of family workers involved in agriculture	0	0	0	-
	Multiactivity (dummy)	0.60	0.87	0.27	0.21
	Other agricultural activities (dummy)	0.53	0.47	0.07	0.72
	Number of years studied	11.33	11.67	-0.33	0.81
	Experience in honey production (years)	17.20	4.67	12.53	0***
	Farm characteristics				
	Number of hives	138.20	11.27	126.93	0***
	Practice of transhumance (dummy)	0.67	0	0.67	0***
	Use of modern hives (dummy)	0.80	0.73	0.7	1
	Use of specialized equipment (dummy)	1	0.33	0.67	0.00**
Tomato	*Household characteristics*				
	Age of head of household (years)	32.6	34.1	-1.5	0.43
	Number of family members involved in agriculture	2.9	1.7	1.2	0.02**
	Multiactivity (dummy)	0	0	0	-
	Multicrop (dummy)	0.53	0	0.53	0.0013***
	Number of years studied	9.87	9.13	0.73	0.46
	Allochthonous (dummy)	0.86	0.73	0.13	-
	Farm characteristics				
	Number of tomato greenhouses	32.00	6.40	25.60	0***
	Access to land by renting (dummy)	1	0.93	0.07	0.33
	Possession of means of transport (dummy)	1	0.60	0.40	0.01***
	Ownership of a tractor (dummy)	0	0	0	-

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Figure 3 - Visualization of the evolution of net profit as a function of farm size.

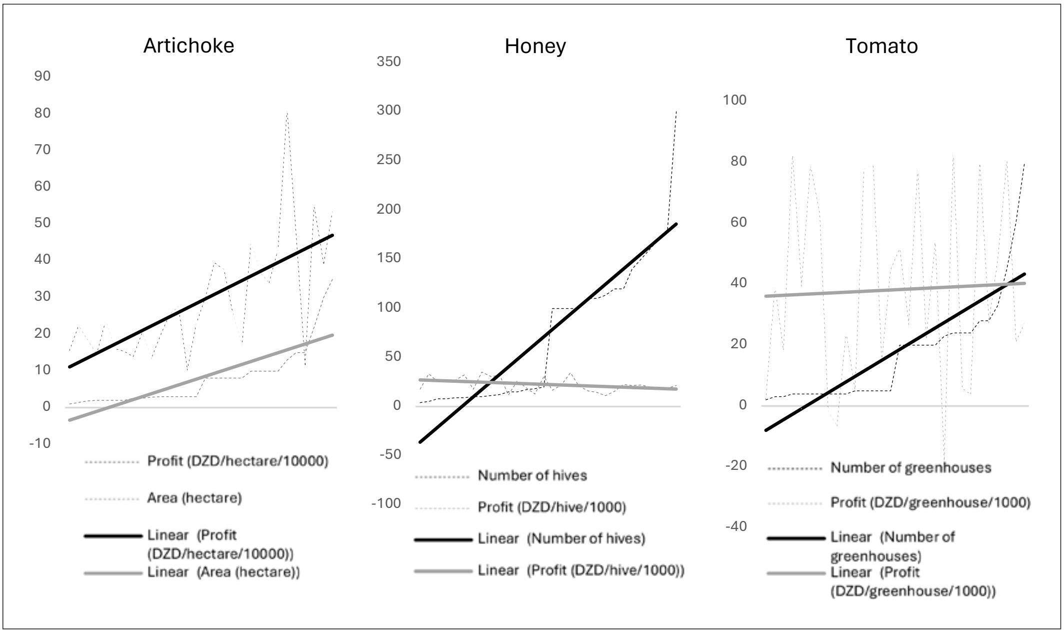


Table 2 - Comparison of performance of small and large producers in the three value chains.

	Variables	*Large farmers*	*Small farmers*	*Difference*	*p-value*
Artichoke	Cost (DZD/hectare)	390,791	379,508	11,284	0.68
	Yield (quintals/hectare)	143	119	24	0.00***
	Price (DZD/kg)	55	47	8	0.00***
	Profit (DZD/hectare)	395,574	185,158	210,416	0.00***
Honey	Cost (DZD/hive)	9,041	6,003	3,037	0.00***
	Yield (kg/hive)	10,6	9,47	1	0.10
	Price (DZD/kg)	2,720	3,286	-566	0.00***
	Profit (DZD/hive)	19,738	25,156	-5,417	0.03**
Tomato	Cost (DZD/greenhouse)	246,542	240,966	5,576	0.71
	Yield (quintals/greenhouse)	30.1	30.2	-1	0.93
	Price (DZD/kg)	93.9	94.2	0	1
	Profit (DZD/greenhouse)	36,805	34,194	2,611	0.67

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

The differences in performance mediators between small and large producers of artichokes and honey can be attributed to certain techno-organizational differences, such as inputs and production and commercial practices. Some of these differences are related to farm size, while others are not. Those attributable to size stem from internal or external configurations or characteristics that favors a specific farm size. These configurations and characteristics act as structural differentiation levers, which we will detail below.

4.3. *Analysis of the size-performance relationship: structural differentiation levers at play*

4.3.1 *Artichoke value chain: levers for a classical positive size-performance relationship*

The structural differentiation levers enabling large artichoke farmers to mobilize more production factors and achieve higher prices include both permanent and temporary factors. These encompass the conditions for granting drilling permits, the structure of the rental land market (primarily consisting of indivisible plots) the artichoke harvest schedule, and the size of buyers in the local market.

As shown in Figure 4, the superior yields of large farmers are attributed to their more effective technical practices, notably supplementary irrigation, a higher number of plants per hectare, and the use of manure. These statistically significant differences are confirmed through linear regression, highlighting the impact of techno-organizational practices on yield.

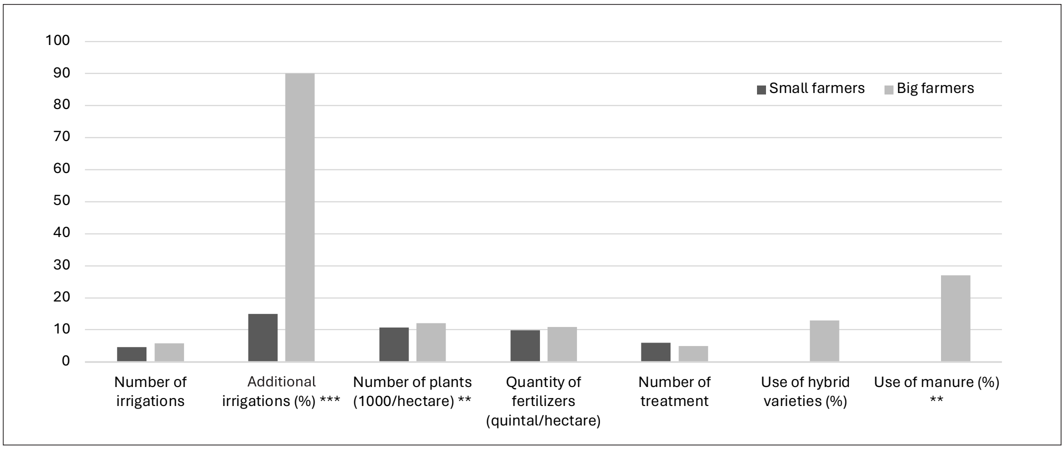
Regression results of various techno-organizational determinants based on adjusted farm size (obtained through linear regression with instrumental variables: total area and number of owned tractors – Equation 3), presented in the Table 3, indicate that only the application of supplementary irrigation is significantly influenced by farm size.

$$\text{Adjusted artichok surface area} = 2{,}8 + (0{,}2 \text{ x total surface area}) + (0{,}5 \text{ x number of tractors}) \quad (3)$$

Large farmers' irrigation practices surpass those of small farmers, particularly in quality. While large farmers conduct an average of two additional irrigations, they primarily perform more supplementary irrigations during dry periods. All plots are within the large irrigated perimeter, which is often inefficient during periods of high-water demand. Access to supplementary irrigation options, such as groundwater, is thus a decisive advantage. Only large farmers, whether landowners or tenants, benefit from boreholes on their plots, as drilling permits are more frequently granted to large farms. Plots with boreholes are often indivisible on the rental market, limiting small farmers' access to groundwater. In the rare cases where plots are divisible, groundwater access remains exclusive to the tenant of the plot containing the borehole. Conversely, small farmers primarily rely on the large irrigated perimeter, facing difficulties during dry periods when it fails to supply water. This lever is temporary and depends on public policies, the rental land market, and the efficiency of the large irrigated perimeter.

Although only two farmers use high-yield hybrid varieties, and the difference between small and large farmers is not significant, these varieties have been recently introduced in the region.

Figure 4 - Comparison of input quantities used by small and large artichoke farmers.



*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Table 3 - Regression results of variations in artichoke production factors based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Additional irrigation	0.27	Intercept	0.03	0.16	0.86	-0.30	0.35
		Adjusted size	0.06	0.02	0.00	0.02	0.09
Number of plants/hectare	0.04	Intercept	11,395	762	0.00	9,834	12,957
		Adjusted size	16.81	80.84	0.84	-148	182
Use of manure	0.03	Intercept	0.68	0.79	0.40	-0.95	2.30
		Adjusted size	0.02	0.08	0.86	-0.16	0.19

They could become a future differentiation lever for large farmers, who generally have greater capacity to test and scale up such innovations.

Although large producers obtain a higher average selling price than small producers (Table 2), the regression between farm size and artichoke selling prices (Table 4) is not statistically significant. This can be attributed to the nature of the director price in this value chain: it is a market-determined selling price, set daily, making most producers – large and small alike – essentially price takers. Consequently, not all large producers consistently secure higher prices, as detailed further in section 5.4.

Nevertheless, the higher prices obtained by certain large producers, which raise the average for the entire large farm category, stem from three main strategic levers. According to respondents, irrigating a few days before harvest results in artichokes with tightly closed bracts, synonymous with higher gustatory and nutritional quality. However, harvesting occurs during the dry season (July), when water resources in the irrigated perimeter are limited. Large farmers, with alternative irrigation options, can irrigate at critical times, delivering superior quality and thus securing higher prices. In contrast, small farmers typically face greater difficulty meeting these quality standards.

Moreover, certain large artichoke producers gain additional bargaining power due to their size and higher production volumes. This advantage primarily arises from two structural elements. First, the local artichoke market lacks a formal wholesale structure and relies heavily on brokers acting as intermediaries. These brokers, remunerated per kilogram traded, prioritize quantity over unit price and actively compete to retain large producers to maximize their commissions, particularly in Oued Rhiou, the main production basin. Being fewer than traders, brokers wield substantial influence, thus enabling advantageous price negotiations for select large producers. Second, the combination of substantial production volumes and a harvesting process typically completed in three operations allows these large farmers to sell significant quantities per transaction. Consequently, these large producers hold a stronger bargaining position with buyers, unlike small farmers, who, constrained by lower volumes, must frequently accept prevailing market terms. In contrast to the tomato value chain, where buyers significantly exceed producers in size and negotiating power, large artichoke farmers enjoy a more balanced relationship with their buyers.

Finally, respondents highlighted that certain large farmers also benefit from stronger networks and closer relationships with market actors, particularly brokers motivated to retain their business. This grants them privileged access to strategic market information regarding prices, demand fluctuations, and optimal sales timing, enabling them to better manage their marketing strategies.

Table 4 - Regression results of variations in artichoke prices based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95.0%*	*Upper 95.0%*
Selling price (DZD/kg)	0.01	Intercept	49.93	3.00	0.00	43	56
		Adjusted size	0.13	0.37	0.73	-0.63	0.88

Small producers, lacking such relationships, are less able to leverage information effectively, limiting their ability to optimize sales.

4.3.2 *Honey value chain: levers supporting an inverse size-performance relationship*

The structural levers enabling small honey producers to better control their costs and sell at higher prices are primarily permanent factors. These include the structure of beekeeping diseases, bee physiology, hive sensitivity to individual care, the compensation of family labor, and the structure of the honey market in Algeria, particularly the perception of artisanal products.

As illustrated in Figure 5, the divergence in production costs favoring small beekeepers stems from significant differences in costs associated with health treatment, feeding, harvesting, transhumance, and packaging.

The regressions of various costs as a function of adjusted size (obtained through linear regression with instrumental variables: the beekeeper's age, beekeeping experience, and engagement in another income-generating activity – Equation 4), presented in Table 5, show that only the costs of health treatment, harvesting, and packaging are significantly influenced by the number of hives.

$$\text{Adjusted number of hives} = 98{,}9 + (-1{,}8 \times \text{age}) + (7{,}4 \times \text{experience}) + (-27{,}9 \times \text{other source of income}) \qquad (4)$$

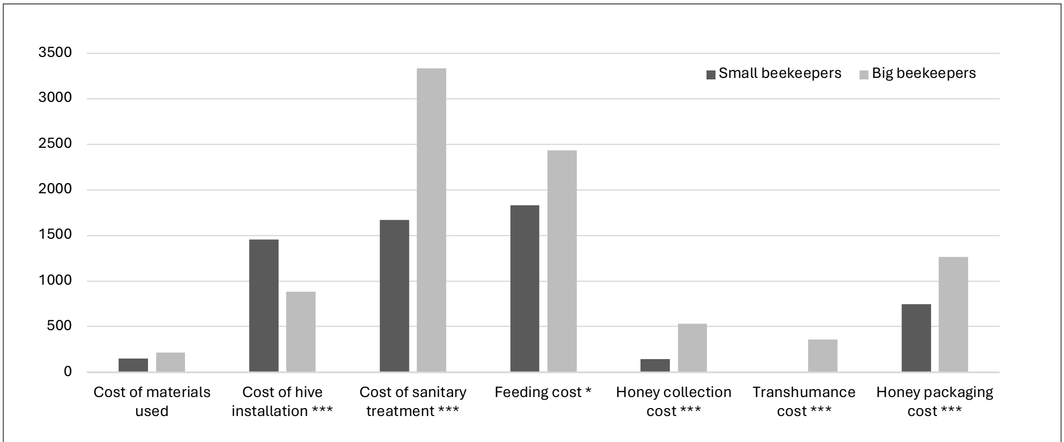
Small beekeepers spend less on health treatment for their hives for three main reasons. First, having fewer hives reduces the concentration of bees in a given area, thereby limiting disease transmission. Additionally, they can monitor each hive more closely and intervene promptly without resorting to mass treatments. Finally, unlike large beekeepers, who are constrained to use low-handling techniques such as chemical treatments with strips, small producers prefer less expensive solutions, such as organic acids or homemade biological remedies, which require frequent applications feasible for small farms.

Similarly, small beekeepers often harvest honey manually, with the help of unpaid family labor, thus reducing costs. In contrast, large producers must hire employees and use specialized equipment.

Finally, small beekeepers often use improvised, low-cost, or free packaging, such as recycled jars, which are accepted by their customers who perceive their products as artisanal. In contrast, large producers are required to purchase specific packaging.

Although small beekeepers achieve higher average selling prices, the regression between hive number (farm size) and honey selling price is not statistically significant (Table 6). Similar to the artichoke value chain, this lack of significance stems from the nature of the director price in the honey value chain: a market-determined selling

Figure 5 - Comparison of costs incurred by small and large honey producers.



*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

Table 5 - Regression results on the variation of different honey production factors and practices based on farm size.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95,0%*	*Upper 95,0%*
Feeding	0,11	Intercept	1,762	247	0.00	1,254	2,269
		Adjusted size	4.96	2.60	0.07	-0.37	10.30
Health treatment	0,22	Intercept	1,613	405	0.00	781	2,444
		Adjusted size	11.88	4.27	0.01	3.14	20.62
Transhumance	0,03	Intercept	15,041	10,316	0.16	-6,091	36,174
		Adjusted size	99	108	0.37	-122	321
Harvesting	0,60	Intercept	-4,003	7,948	0.62	-20,285	12,278
		Adjusted size	554	83	0.00	383	726
Packaging	0,24	Intercept	745	111	0.00	518	973
		Adjusted size	3.49	1.17	0.01	1.10	5.88

Table 6 - Regression results of variations in honey prices and direct retail sales practices based on the number of hives.

	R Square		*Coefficients*	*Standard Error*	*P-value*	*Lower 95,0%*	*Upper 95,0%*
Selling price (DZD/kg)	0,22	Intercept	2,890	128	0.00	2,628	3,152
		Adjusted size	1.51	1.23	0.23	-1.00	4.02
Direct retail sales	0,54	Intercept	0.99	0.11	0.00	0.77	1.21
		Adjusted size	-0.01	0.00	0.00	-0.01	-0.01

price, at which both small and large producers generally remain price takers. Thus, not all small beekeepers consistently secure higher prices, as explained further in section 5.4.

Nevertheless, the price advantage of other small producers, which also raises the average selling price for their category, is largely attributable to their direct retail sales practices. This practice constitutes the most notable and statistically significant difference in commercial practices between small and large beekeepers. According to regression analysis (Table 6), engaging in direct retail sales significantly increases the honey price by approximately 635 DZD/kg, and is strongly influenced by the adjusted operational size of the beekeeper.

The significant impact of retail sales on honey prices in Algeria relates directly to specific market characteristics. Given the absence of formal mechanisms for verifying agricultural product quality, consumers highly value personal verification, particularly for expensive products such as honey, which in 2023 was priced on average 60 and 33 times higher than artichokes and tomatoes, respectively. In this context, purchasing honey directly from producers serves as an informal guarantee of quality.

Consequently, small producers, due to their lower production volumes, predominantly sell honey directly to consumers, emphasizing its artisanal quality. This short supply chain allows them to capture intermediary margins while effectively branding their honey as handcrafted and authentic. Conversely, larger producers, constrained by higher production volumes, rely on longer distribution channels involving wholesalers and retailers, resulting in lower wholesale prices and reduced opportunities to ensure the perceived artisanal quality of their honey.

4.3.3. *Tomato value chain: lack of levers and neutralization of the size-performance relationship*

The profits of small and large tomato farmers are similar due to comparable yields, costs, and selling prices. This homogeneity stems from the identical production and marketing practices shared by both groups.

Small and large farmers employ closely aligned technical pathways, with statistically insignificant differences. Nearly all farmers access land through rental agreements and use boreholes for irrigation, performing a similar number of irrigations (28 for large farmers, 24 for small farmers). All use tunnel greenhouses, hybrid varieties, and similar inputs: approximately 8 quintals of fertilizer, 12 and 13 quintals of manure per greenhouse, and 11 phytosanitary treatments per season.

Two factors explain this uniformity. First, all producers have equitable access to divisible resources such as water and land, rented by greenhouse unit, or inputs available in small quantities (e.g., manure sold by trailer). This divisibility, a structural feature for decades, ensures accessibility for all. Second, neither group benefits from major innovations unavailable to the other. The absence of innovation as a differentiation factor is not structural. The last significant innovation, the hybrid variety Tofane, introduced in the late 2000s, temporarily advantaged large farmers, increasing their yields by 18% and profits by 59%. However, this innovation has since become widely adopted.

On the commercial front, small and large farmers exhibit similar behaviors towards buyers. The high perishability of tomatoes plays a central role in shaping these practices. Unlike artichokes, whose harvests can be delayed by a few days to avoid unfavorable market conditions, and honey, which can be stored for extended periods without loss of quality, tomatoes must be harvested progressively as they ripen. This perishability leads farmers to carry out numerous small harvest operations (14 on average), resulting in modest transaction volumes at each sale. It also puts them under constant pressure to sell quickly, limiting their ability to negotiate and pushing them to accept similar trading conditions regardless of farm size. In terms of daily trade volumes, farmers are 4 to 12 times smaller than the average wholesalers at the El Ghrous market. This power imbalance, which is not entirely structural, has intensified over the past decade, with a 30% increase in traders' purchasing capacities between 2013 and 2023. This disparity is reflected in the average profits achieved in 2023: 27.4 DZD/kg of tomato for wholesalers compared to 14 DZD/kg of tomato for farmers.

4.4. *Assessment of farms' activation capacities*

The effectiveness of structural differentiation levers relies on farms' ability to activate them to enhance their performance. Not all producers, even in favorable contexts, fully utilize these assets optimally. Some farms, despite their advantageous size, have failed to meet the necessary conditions to leverage these levers, resulting in profits lower than the average benefit achieved by disadvantaged producers (Table 7).

This failure notably concerns the inability to activate levers related to selling prices, which explains the lack of statistical significance in the direct regressions between farm size and selling prices observed in both the artichoke and honey value chains.

Indeed, three large artichoke farmers, who achieved low profits, sold their produce at a price 27% lower than other large farmers. This stems from their inability to harvest independently due to a lack of suitable labor in their locality. Consequently, they are compelled to sell standing crops to a small group of traders with access to specialized seasonal workers. In addition to conceding an extra margin for harvesting, this reduces their pool of clients, thereby weakening their bargaining power – an essential structural differentiation lever within this value chain.

Similarly, five small honey producers, who also reported low profits, sold their products at an average price 14% lower than their peers. Favoring other time-consuming activities, they rely on local shops to market their products, which limits the artisanal value addition and access to retail prices. Furthermore, their yields – 47% lower than their peers – reflect inadequate sanitary management caused by their low presence on the farm. This situation prevents them from activating the levers of retail sales and sanitary risk management.

Moreover, no theoretically disadvantaged farmers (small artichoke producers and large

Table 7 - Comparison of performance between advantaged producers who achieved high profits and those who did not.

	Artichoke			*Honey*		
	Large farmers with better profits than the average profit of small farmers	*Large farmers with profits lower than the average profit of small farmers*	*p-value*	*Small farmers with better profits than the average profit of large farmers*	*Small farmers with profits lower than the average profit of large farmers*	*p-value*
Profit (DZD/hectare or hive)	449,985	177,933	0.45***	29,839	15,790	7.52***
Price (DZD/kg)	57	45	0.63**	3,430	3,000	2.03**
Yield (kg/hectare or hive)	14,792	12,500	0.23	10.6	7.2	4.29***
Cost (DZD/hectare or hive)	394,348	376,566	0.88	6,100	5,809	0.27

*Levels of significance: *p < 0.1; **p < 0.05; ***p < 0.01.*

honey producers) activated these levers, consistently recording profits below those of their advantaged counterparts. This confirms that while a favorable size alone is insufficient, it remains indispensable for leveraging these structural differentiation levers and maximizing profits.

5. Discussion

This study brings new insights into the size–performance relationship in agriculture, a domain marked by fragmented and often contradictory findings (Eastwood *et al*., 2010). While the literature has identified several influencing factors, it lacks a unified analytical framework. To address this gap, we introduce the concept of "*structural differentiation levers*," a common label for heterogeneous factors that initiate size-performance effects. These levers demonstrate that the relationship is contextual, non-linear, and activated under specific conditions. Unlike earlier works focusing on isolated variables (Ali and Deininger, 2015), this study proposes a comprehensive framework that integrates these factors and accommodates local contexts, contributing to a more coherent understanding of the mechanisms behind size-related advantages.

Large artichoke farms benefit from productive and qualitative advantages not only due to classical economies of scale (mechanization, input efficiency – Deininger *et al*., 2018), but also because of structural elements like land configuration and favorable market access. Their access to borehole-equipped plots, essential for irrigation in semi-arid regions, is a critical advantage, especially for sensitive crops like artichokes. This aligns with findings by Assunção and Braido (2007) on differentiated water access for large farms, though few studies focus on vegetables. Our findings also echo Assassi (2023), who notes large farmers' access to healthier land, while contrasting with Barrett *et al*. (2010), who argue small farmers often benefit from better-located plots. Other levers include resource management and harvest timing, which allow larger farms to optimize quality and align production with high-price periods – a mechanism mentioned in World Bank (2016), though underexplored in local vegetable markets.

Similarly, small beekeepers in eastern Algiers show distinct advantages over large operations, particularly in cost control, consistent with Barrett *et al*. (2010). They use internal resources like family labor to maintain profitability, unlike larger farms that rely on outsourcing, which raises costs. A key, under-studied lever is direct sales: small producers use short supply chains to sell high-priced artisanal products. Additionally, although small producers are often seen as having weaker sanitary controls (Morris *et al*., 2023), our results show a more nuanced situation. With fewer hives, they apply targeted treatments more effectively and at lower cost.

The observed parity between small and large tomato producers illustrates a neutral size-performance relationship – meaning size has no direct impact on productivity or profit. This rare finding is in line with Benmehaia (2022), who notes that without structural triggers, no differentiation emerges. Our study advances this by showing how these triggers evolve over time and across space, as suggested by Rada and Fuglie (2019), who highlight the transformative role of technology and policy. In our case, uniform access to inputs (water, seeds, credit) and standardized practices explain the uniformity in performance, resembling Gourlay *et al*. (2017), where similar inputs ensure similar yields across farm sizes. This contrasts with Huang and Wang (2024), who show significant disparities in China due to unequal access to capital and technology. The absence of technological change in the studied tomato chain limits scale-based advantages, unlike other chains where tech adoption quickly favors large farms (Rada and Fuglie, 2019).

Finally, consistent with Colin and Bouquet (2022), this study confirms that the size–performance relationship is neither universal nor linear – it depends on chain-specific and contextual triggers. Where levers are present, they create size-based differentiation; where absent, they suspend it. These findings stress the importance of examining underlying mechanisms to fully grasp the dynamics of this relationship.

6. Conclusion

This article aimed to determine whether the relationship between farm size and performance reflects a systematic pattern or is shaped by specific contexts. Relying on comparative evidence from three Algerian value chains (artichoke, honey, and tomato) and combining quantitative and qualitative analysis, the study identified a consistent explanatory mechanism despite differing relationship types across chains.

Rather than focusing solely on performance gaps between farm sizes, the analysis highlights the contextual conditions – referred to as structural differentiation levers – that shape these gaps. These levers, which vary by chain, include resource access, institutional arrangements, and commercialization channels. Their presence, alignment with farm size, and activation by farmers determine whether size translates into performance advantages.

These findings hold practical implications for public policy. While farmers operate within constraints, in addition to guiding policymakers in promoting one production model over another, they can also influence the underlying levers, such as access to water, land, and markets, to create more balanced or strategically differentiated support systems across farm sizes, in a more equitable or efficient direction.

The study's scope is limited to three chains and a single production year, which restricts its temporal and spatial generalizability. Future work should expand to other contexts and adopt a longitudinal lens to assess how these structural levers evolve and condition the size–performance relationship over time.

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