



Original Research

Factors Associated with Perceived Resilience Among Date-palm Farms in the M'Hamid El Ghizlane Oasis, Morocco: A Cross-sectional Study

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Abstract

Oasis farming faces climatic, hydrological, and institutional pressures, yet farmers' perceived resilience remains poorly documented. This study assessed a nine-item resilience scale and associated factors among date-palm farms in M'Hamid El Ghizlane, Morocco. A cross-sectional survey of randomly selected decision-makers (April–June 2024) obtained 260 responses (response rate: 52%), with potential non-response bias. Reliability and ordinal factor analyses were combined with HC3-robust multiple regression of ten prespecified predictors and sensitivity analyses. The mean score was 18.12/45 (SD = 5.02); 71.9% of farms had low and 28.1% moderate perceived resilience; none was high. Reliability was satisfactory ($\alpha = 0.829$; $\omega = 0.915$), and the three-factor model showed acceptable sample-specific fit (CFI = 0.989; TLI = 0.983; RMSEA = 0.050; SRMR = 0.045). The regression explained 15.1% of score variance, leaving 84.9% unexplained. Education ($B = 1.681$, $p < 0.001$) and age ($B = 0.116$, $p = 0.004$) were positively associated with the score. Cooperative membership showed no robust association across sensitivity analyses. Farm size, diversification, modernised irrigation, public support, and climate-risk awareness were not independently associated with the global score. These findings identify local correlates of perceived farm-level resilience without establishing causality or measuring collective oasis resilience.

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Statement of Sustainability: This study combines a psychometrically assessed measure of farm-level perceived resilience with locally grounded evidence from a hyperarid oasis. Its findings may inform discussions of resilient agricultural livelihoods (SDG 2) and future research on water-related constraints (SDG 6), with possible relevance to climate adaptation (SDG 13). These potential contributions remain limited to informing research and policy discussions, given the single-site, cross-sectional design and the absence of direct measures of water governance or sustainability outcomes.

1. Introduction

In arid and semi-arid regions, oasis systems face recurrent droughts, rising temperatures, water scarcity, and land degradation. These pressures interact with economic, demographic, and institutional changes that threaten agricultural continuity and local livelihoods (Intergovernmental Panel on Climate Change [IPCC], 2023; Leal Filho et al., 2024). An oasis is therefore not merely a productive space exposed to climatic hazards, but a social-ecological system in which natural resources, users, farms, and institutions are interdependent (Folke, 2006; Ostrom, 2009). Within this framework, the present study examines farm-level perceived resilience, defined through the main decision-maker's assessment of the farm's capacities, rather than collective oasis resilience. Water is central to this interdependence. As a common-pool resource and production factor, its use by one farm affects access for others. Oasis irrigation has historically relied on allocation rules, rotational water-sharing, and collective maintenance and control. These arrangements are being transformed by individual pumping, groundwater overexploitation, and changing land-tenure relations (Silva-Novoa Sánchez et al., 2022). Their relevance to farm decisions requires distinguishing individual perceptions from the functioning of the wider oasis system while recognising interactions between these two levels of analysis.

Resilience analysis must consequently connect farm capacities with collective conditions. In social-ecological systems, resilience denotes the capacity to maintain essential functions under disturbance, adapt operations, and transform when existing structures



become untenable (Folke, 2006). In agriculture, it encompasses robustness, adaptability, and transformability and emerges through interactions among productive resources, knowledge, networks, institutions, and the biophysical environment (Darnhofer et al., 2016; Meuwissen et al., 2019). This relational and multidimensional character complicates measurement. Technical and economic indicators describe available resources but only partly capture how farmers assess their capacity to maintain activities, manage unexpected events, and prepare for change. Perceived resilience addresses this dimension by recording actors' assessments of their own capacities, providing a complementary perspective to external assessments of vulnerability (Jones and Tanner, 2017). Such perceptions vary with farmer and farm characteristics, learning opportunities, resources, and support networks (Prat-Benhamou et al., 2024; Spiegel et al., 2021), but should not be equated with post-shock performance or collective territorial resilience. Here, water-allocation rules, power relations, and conflict-resolution mechanisms form part of the institutional context, but are not directly measured; their explanatory role therefore remains untested.

Research on Moroccan oases has primarily addressed environmental degradation, water governance, ecosystem services, agro-diversity, and socioeconomic transformation. At M'Hamid El Ghizlane, vegetation cover contracted markedly between 1984 and 2016 (Ait Lamqadem et al., 2017). Across Moroccan oasis settings, recent studies document climatic pressures on date-palm cultivation, changing rural-urban relations and knowledge transmission, differing perceptions of water-related ecosystem services, and agrodiversity (Boubou et al., 2025; Bouzelmate et al., 2025; Houssni et al., 2023; Mahjoubi et al., 2022). Research in the Middle Drâa Valley has also identified limitations in integrated water governance and unequal access to modernisation programmes (Silva-Novoa Sánchez et al., 2022). Moreover, drip irrigation does not necessarily reduce total withdrawals because plot-level savings may be offset by production intensification or irrigated-area expansion (Molle and Tanouti, 2017). These findings provide context for examining farm perceptions, rather than evidence of the mechanisms underlying them. The specific gap addressed here is the limited evidence on the joint adjusted associations between farm-level perceived resilience and human capital, productive resources, farming practices, support services, organisational affiliation, and climate-risk awareness among date-palm farms in M'Hamid El Ghizlane.

The farm, represented by its main decision-maker, constitutes the unit of analysis. The study asks which factors are associated with the perceived resilience of date-palm farms in M'Hamid El Ghizlane. It estimates adjusted associations between a composite perceived-resilience score and decision-maker characteristics, productive resources and practices, support services, cooperative membership, and climate-risk awareness. Its contribution is to combine a preliminary, sample-specific psychometric assessment of a multidimensional resilience measure with farm-level explanatory analysis in a Moroccan oasis. Positive associations are expected for education and agricultural training, reflecting the potential relevance of knowledge and learning. Cultivated area, diversification, modernised irrigation, public support, cooperative membership, and climate-risk awareness are also expected to show positive associations. Age and sex are controls without directional hypotheses. Education, irrigation, diversification, and cooperative membership represent human capital, a productive asset, a farming practice, and organisational affiliation, respectively. Their novelty, adoption dates, and diffusion were not measured. The analysis therefore examines these characteristics without treating them as direct measures of innovation or presuming that their presence necessarily improves resilience. Given the cross-sectional design, the estimated relationships are interpreted as associations rather than causal effects.

2. Materials and Methods

2.1. Study Area and Level of Analysis

The study was conducted in M'Hamid El Ghizlane, Zagora Province, Drâa-Tafilalet Region, south-eastern Morocco (HCP, 2016). Its main settlement lies at approximately 29°49'12"N 5°43'12"W, at the southern end of the Drâa Valley near the Sahara Desert. The area has a hyperarid climate, with mean annual rainfall of approximately 54 mm, annual evaporation approaching 3,000 mm, and summer temperatures exceeding 48 °C. Drought, soil salinisation, and sand encroachment place substantial pressure on agricultural land and oasis vegetation (Ait Lamqadem et al., 2017).

Local farming is dominated by date palm (*Phoenix dactylifera* L.), combined with subsistence and vegetable crops and small-scale livestock keeping. The site was selected because of its climatic exposure, dependence on date-palm farming, increasing water constraints, and documented vegetation decline (Figure 1).

The unit of analysis was the farm, represented by its main decision-maker for production, irrigation, and resource allocation. The outcome therefore measures the main decision-maker's assessment of the farm's capacity to maintain activities, manage unexpected events, and prepare for adaptation. It captures farm-level perceived resilience rather than the collective resilience of the oasis. Water-allocation rules, power relations, participation in collective decisions, and conflict-resolution mechanisms were treated as contextual dimensions but were not directly measured. This boundary is consistent with the relational and multilevel conception of farm resilience proposed by Darnhofer et al. (2016).

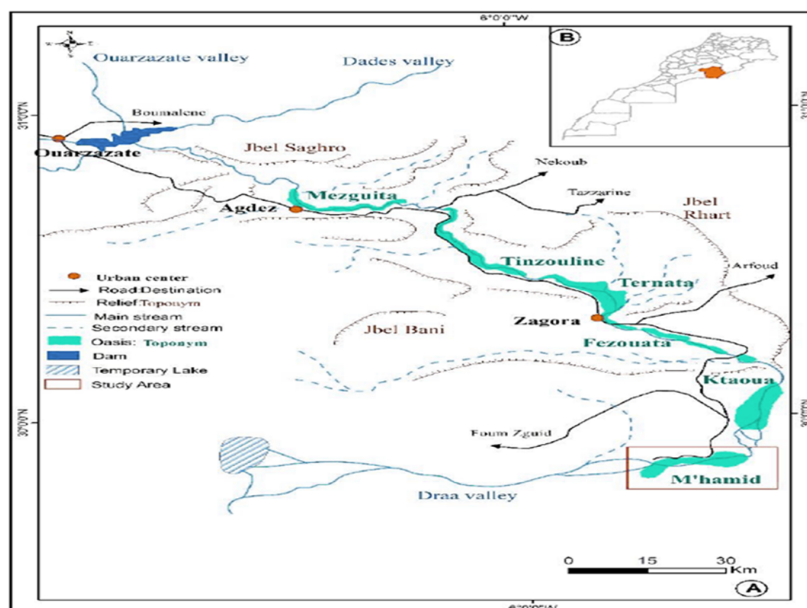


Figure 1. Location of the Middle Drâa Valley and the M'Hamid El Ghizlane study area in south-eastern Morocco.

2.2. Research Design, Sampling, and Data Collection

A quantitative cross-sectional survey was conducted between April and June 2024 among households operating date-palm farms in M'Hamid El Ghizlane. Eligible participants were the main decision-makers involved in production, irrigation, and farm management; households without date palms and individuals not involved in these decisions were excluded.

The sampling frame was an ORMVAO administrative register covering the municipality and listing 765 eligible households (ORMVAO, 2024). For this finite population, a 95% confidence level, an assumed proportion of 0.50, and a 5% margin of error yielded a minimum sample of approximately 256 households (Cochran, 1977). To anticipate non-response, 500 households were selected by simple random sampling using Microsoft Excel. The survey produced 260 usable questionnaires, corresponding to a 52% response rate. Of the 240 non-participants, 168 were absent and 72 declined participation. Because socioeconomic data were unavailable for non-participants, respondents and non-respondents could not be compared. Consequently, neither the direction nor the magnitude of potential non-response bias could be assessed. Such bias cannot be excluded, and the representativeness of the achieved sample cannot be established solely from the initial random selection. All face-to-face interviews were conducted by the principal investigator using a structured questionnaire covering socioeconomic characteristics, productive resources and farming practices, access to organisations and support services, climate-risk awareness, and perceived farm resilience. Questions were neutrally worded to avoid suggesting preferred responses. Interviews were administered in Moroccan Arabic or Amazigh according to participants' preferences. The wording was orally adapted and assessed for comprehension during a pretest with 20 farmers who were excluded from the final sample; no substantive changes were required. No independent forward- and back-translation procedure was undertaken. Interviews lasted 30–40 min, and data entered in Microsoft Excel were checked twice against the original questionnaires. Information on the explanatory variables and perceived farm-level resilience was collected from the same respondent during the same interview, leaving the study potentially exposed to common-method bias (Podsakoff et al., 2003). Institutional authorisation was obtained before data collection. No formal numbered ethics committee approval was issued. Participants received an oral explanation of the study and provided informed oral consent. Participation was voluntary, uncompensated, and could be discontinued at any time. Questionnaires were anonymised, and data were processed confidentially and reported only in aggregate form. Documentation of the institutional authorisation is available confidentially to the editorial office upon request. The structured questionnaire, neutral wording, comprehension pretest, anonymisation, and confidential data handling constituted procedural safeguards; however, these measures do not, by themselves, establish the absence of common-method bias.

2.3. Measurement of Perceived Resilience and Explanatory Variables

Farm-level perceived resilience was defined as the main decision-maker's assessment of the farm's capacity to maintain essential activities under disturbance, manage unexpected events, and prepare for future adaptation (Darnhofer et al., 2016; Jones and Tanner, 2017; Spiegel et al., 2021). These contributions informed nine study-specific items addressing date-palm farm activities and management decisions, with three items per dimension. The instrument was not reproduced from an existing validated scale.



Development did not include an independent expert-review stage. Items were orally adapted into Moroccan Arabic or Amazigh and pretested for comprehension with 20 farmers; no substantive revisions were required. No independent forward- and back-translation was undertaken. Responses ranged from 1 (“strongly disagree”) to 5 (“strongly agree”). All items were positively coded, with higher values indicating greater perceived resilience. Item wording, translations, dimensional allocation, and coding are provided in Supplementary Table S1. For farm i , the global score was calculated as:

$$R_i = \sum_{k=1}^9 x_{ik}; 9 \leq R_i \leq 45 \quad (1)$$

where x_{ik} denotes the response of farm i to item k . Dimension scores ranged from 3 to 15 and the global score from 9 to 45. All 260 respondents completed the nine items; therefore, no imputation was required. Item R4 showed limited variability, with responses concentrated in two categories, but was retained for its conceptual contribution to unexpected-event management, its standardised loading of 0.715, and preservation of three items per dimension. Sensitivity analyses excluding R4 examined the three-factor model’s fit, dimensional reliability, and regression estimates. The global score was treated as a pragmatic composite rather than evidence of strict unidimensionality. Separate regressions for the three dimensions were conducted as sensitivity analyses. Ten prespecified predictors comprised age, education, sex, cultivated area, crop diversification, modernised irrigation, agricultural training, public support, cooperative membership, and climate-risk awareness. Definitions, coding, and reference categories are reported in Supplementary Table S2. Age and sex were control variables. Education and climate-risk awareness were initially modelled as ordinal scores and subsequently as categorical indicators in sensitivity analyses. Cooperative membership indicated organisational affiliation, not participation in collective water governance. Land tenure, climate-related concern, and perceived vulnerability were retained for descriptive purposes only. No automatic variable selection based on statistical significance was applied.

2.4. Statistical Analysis

Analyses were conducted using Python 3.12.13 with pandas 2.2.3, NumPy 2.3.5, SciPy 1.17.0, and openpyxl 3.1.5. Data screening covered coding consistency, out-of-range values, and missingness; all 260 records were complete. Descriptive statistics comprised frequencies and percentages, means and standard deviations, or medians and interquartile ranges, as appropriate. Internal consistency was assessed using conventional and ordinal Cronbach’s alpha and McDonald’s total omega (Cronbach, 1951; McDonald, 1999). Psychometric evaluation was treated as an exploratory-confirmatory assessment of a new instrument in a single sample, without independent validation. The prespecified three-factor model was compared with a one-factor model using polychoric correlations and diagonally weighted least squares. A mean- and variance-adjusted χ^2 statistic was used, with the covariance matrix estimated from 3,000 non-parametric bootstrap replications using a fixed seed of 20260815 (Li, 2016). Fit was assessed jointly using CFI, TLI, RMSEA with its 90% confidence interval, and SRMR; values around ≥ 0.90 for CFI/TLI and ≤ 0.08 for RMSEA/SRMR were treated as indicative guidelines (Hu and Bentler, 1999). Convergent validity was assessed using standardised factor loadings, composite reliability, and average variance extracted, with reference values of 0.70 for composite reliability and 0.50 for average variance extracted (Fornell and Larcker, 1981). Models were compared across all fit indices without directly subtracting their adjusted χ^2 statistics. The three-factor model and reliability estimates were reassessed after excluding R4, using the same estimation procedure. A Harman-style diagnostic used unrotated principal component analysis of the Pearson correlation matrix of the nine resilience items and ten predictors, followed by an analysis restricted to the nine items. A first component explaining more than 50% of total variance was considered a heuristic indication of dominance. Given the heterogeneous measures and the procedure’s limitations, this supplementary diagnostic could neither establish nor exclude common-method bias (Fuller et al., 2016; Podsakoff et al., 2024). The primary analysis used the continuous resilience score to retain its full 9–45 range:

$$R_i = \beta_0 + \sum_{k=1}^{10} \beta_k X_{ik} + \varepsilon_i \quad (2)$$

Here, R_i denotes the score for farm i , X_{ik} explanatory variable k , β_0 the intercept, β_k its adjusted coefficient, and ε_i the error term. The ten prespecified predictors described in Section 2.3 and Supplementary Table S2 were entered simultaneously into a multiple linear regression. Results were reported as unstandardised and standardised coefficients with HC3 robust standard errors, 95% confidence intervals, and two-sided p-values. HC3 standard errors were selected a priori, before examining the Breusch–Pagan test results, to accommodate potentially unequal error variances and account for leverage in covariance estimation (Long and Ervin, 2000). Model performance was assessed using R^2 , adjusted R^2 , and a robust Wald test. Variance inflation factors, the Breusch–Pagan test, residual diagnostics, and Cook’s distance informed model assessment; Breusch–Pagan was used as a diagnostic. The threshold 4/n was used only as an exploratory Cook’s-distance criterion, and observations were not automatically excluded (Breusch and Pagan, 1979; Cook, 1977). For sensitivity analysis, the score was classified as low (9–21), moderate (22–33), or high (34–45). These analytical categories were neither validated nor normative. Because no farm belonged to the high category, binary logistic regression contrasted moderate with low resilience:



$$D_i = \begin{cases} 1 & \text{if } 22 \leq R_i \leq 33 \\ 0 & \text{if } 9 \leq R_i \leq 21 \end{cases} \quad (3)$$

The model was estimated by maximum likelihood and reported as adjusted odds ratios with 95% confidence intervals. Performance was evaluated using the likelihood-ratio test, Nagelkerke's pseudo- R^2 , and the apparent area under the ROC curve (Nagelkerke, 1991). There were 73 events (moderate resilience) for ten predictor parameters, equivalent to approximately 7.3 events per parameter. The model was therefore treated as a secondary, potentially imprecise analysis; categorisation also reduces information and statistical power (Altman and Royston, 2006). Further sensitivity analyses excluded potentially influential observations, modelled the three resilience dimensions separately, tested the modernised-irrigation $\times$ cooperative-membership interaction, repeated the regression using the eight-item score without R4, and treated education and climate-risk awareness as categorical variables. Statistical significance was set at 5%. Given the cross-sectional design, coefficients were interpreted as adjusted associations rather than causal effects. Detailed analytical procedures and supplementary numerical results are provided in Supplementary File S2.

3. Results and Discussion

3.1. Characteristics of Surveyed Farms and Distribution of perceived Resilience

The main decision-makers averaged 52.45 years, and 96.9% were men. Educational attainment was low: 49.2% had no formal education and only 19.6% had reached secondary or higher education. Farms were generally small (median cultivated area: 1.00 ha), and only 28.1% cultivated at least two crops. Modernised irrigation, agricultural training, public support, and cooperative membership concerned 47.7%, 46.9%, 40.8%, and 60.8% of respondents, respectively (Table 1).

Table 1. Characteristics of the main decision-makers and surveyed farms (N = 260).

Characteristic	Result
Age of main decision-maker	52.45 $\pm$ 9.98 years
Sex	Male: 252 (96.9%); female: 8 (3.1%)
Education	None: 128 (49.2%); primary: 81 (31.2%); secondary: 47 (18.1%); higher: 4 (1.5%)
Cultivated area	Mean: 1.53 $\pm$ 1.29 ha; median: 1.00 ha [IQR: 0.60–2.00]
At least two crops	73 (28.1%)
Modernised irrigation	124 (47.7%)
Agricultural training	122 (46.9%)
Public support	106 (40.8%)
Cooperative membership	158 (60.8%)
Climate-risk awareness	Low: 103 (39.6%); moderate: 100 (38.5%); high: 57 (21.9%)

Note: Categorical variables are presented as frequencies and percentages. Continuous variables are presented as mean $\pm$ standard deviation or median [interquartile range]. IQR = interquartile range; ha = hectare.

The overall resilience score averaged 18.12 (median = 17.50; observed range = 9–32) on the theoretical 9–45 scale, remaining well below the midpoint of 27 (Table 2). Dimension means were highest for future anticipation and planning (6.79), followed by managing unexpected events (5.85) and maintaining activities under shocks (5.48); all were below the theoretical midpoint of 9. These descriptive differences were not subjected to statistical comparison.

Table 2. Distribution of perceived-resilience scores (N = 260).

Score	Mean $\pm$ SD	Median [IQR]	Observed range
Maintenance of farming activities when confronted with shocks	5.48 $\pm$ 2.17	5.00 [3.00–7.00]	3–11
Management of unexpected events	5.85 $\pm$ 1.83	6.00 [4.00–7.00]	3–11
Anticipation and planning for the future	6.79 $\pm$ 2.19	7.00 [5.00–8.00]	3–12
Overall perceived-resilience score	18.12 $\pm$ 5.02	17.50 [14.00–22.00]	9–32

Note: SD = standard deviation; IQR = interquartile range. The theoretical range is 3–15 for each dimension and 9–45 for the overall score.

Under the predefined analytical categorisation, 187 farms (71.9%) had low and 73 (28.1%) moderate perceived resilience; none was classified as having high perceived resilience. The cut-offs defining these categories are neither validated nor normative and do not establish objective farm resilience. The scores reflect farmers' perceived adaptive capacities rather than performance observed after an actual shock (Jones and Tanner, 2017). The concentration of scores at the lower end of the scale is consistent with documented water scarcity, salinisation, sand encroachment, vegetation decline, and climate-related pressures on date-palm farming in the Drâa-Tafilalet oases (Ait Lamqadem et al., 2017; Bouzelmate et al., 2025). Adaptation opportunities also vary with location and access to water-related ecosystem services (Mahjoubi et al., 2022). These contextual similarities do not establish causation. Before



examining the factors associated with these score differences, the reliability and dimensional structure of the perceived-resilience instrument were assessed.

3.2. Psychometric Properties of the Perceived-Resilience Scale

The nine-item scale showed satisfactory internal consistency (conventional $\alpha = 0.829$; ordinal $\alpha = 0.878$; total $\omega = 0.915$). Reliability was lowest for managing unexpected events (conventional $\alpha = 0.613$; ordinal $\alpha = 0.752$), and item R4 showed restricted variability, with only two response categories used.

Table 3. Internal consistency, convergent validity, and fit of the perceived-resilience measurement models (N = 260) (Panel A. Internal consistency and convergent validity).

Dimension / scale	Standardised factor loadings	Conventional α	Ordinal α	CR	AVE
Maintenance of farming activities when confronted with shocks	R1 = 0.861; R2 = 0.687; R3 = 0.903	0.780	0.857	0.861	0.676
Management of unexpected events	R4 = 0.715; R5 = 0.660; R6 = 0.753	0.613	0.752	0.753	0.505
Anticipation and planning for the future	R7 = 0.740; R8 = 0.910; R9 = 0.754	0.760	0.829	0.845	0.648
Overall scale	—	0.829	0.878	—	—
Maintenance of farming activities when confronted with shocks — model without R4	R1 = 0.866; R2 = 0.696; R3 = 0.891	0.780	0.857	0.861	0.676
Management of unexpected events — model without R4	R5 = 0.638; R6 = 0.723	0.543	0.631	0.634	0.465
Anticipation and planning for the future — model without R4	R7 = 0.735; R8 = 0.911; R9 = 0.756	0.760	0.829	0.845	0.647
Overall scale without R4	—	0.823	0.868	—	—

Table 4. Internal consistency, convergent validity, and fit of the perceived-resilience measurement models (N = 260) (Panel B. Fit of the confirmatory factor models)

Model	χ^2	df	p	CFI	TLI	RMSEA [90% CI]	SRMR
One-factor	170.09	27	< 0.001	0.898	0.864	0.143 [0.123–0.164]	0.098
Three-factor	39.66	24	0.023	0.989	0.983	0.050 [0.019–0.077]	0.045
Three-factor without R4	34.23	17	0.008	0.986	0.978	0.063 [0.031–0.093]	0.045

Note: α = Cronbach's alpha; ω = McDonald's total omega; df = degrees of freedom; CR = composite reliability; AVE = average variance extracted; CFI = comparative fit index; TLI = Tucker–Lewis index; RMSEA = root mean square error of approximation; CI = confidence interval; SRMR = standardised root mean square residual. The first four rows of Panel A concern the nine-item model. Ordinal α and model-based ω refer to latent-response correlations. Overall ω was 0.915 with nine items and 0.907 without R4. χ^2 = chi-square statistic; p = p-value. Comparisons between models with different item sets are descriptive.

Standardised loadings ranged from 0.660 to 0.910, composite reliability exceeded 0.75, and average variance extracted ranged from 0.505 to 0.676 in the nine-item model. These values provided preliminary evidence of convergent validity, although the management of unexpected events showed comparatively weaker measurement properties. The three-factor model showed acceptable sample-specific fit, whereas the one-factor model performed inadequately (Tables 3 and 4). The overall pattern of indices, rather than direct subtraction of the adjusted χ^2 statistics, therefore favoured the three-factor structure. In the Harman-style diagnostic, the first component explained 26.33% of total variance across the nine resilience items and ten predictors, and 43.82% when restricted to the nine items. Although both values were below the 50% heuristic threshold, this limited diagnostic does not exclude common-method bias (Podsakoff et al., 2024). Excluding R4 did not improve the overall pattern of fit: CFI and TLI were slightly lower, RMSEA increased, and SRMR remained approximately unchanged. Standardised loadings ranged from 0.638 to 0.911. For management of unexpected events, conventional α decreased from 0.613 to 0.543, ordinal α from 0.752 to 0.631, and CR from 0.753 to 0.634. These descriptive findings supported retaining R4, alongside its loading of 0.715, its conceptual contribution to unexpected-event management, and the preservation of three items per dimension. Its restricted variability nevertheless remains a measurement limitation. Factor correlations of 0.608–0.710 were consistent with related resilience dimensions, in line with multidimensional conceptualisations of farm resilience (Meuwissen et al., 2019; Prat-Benhamou et al., 2024; Spiegel et al., 2021). The overall score was retained as a pragmatic composite; high total omega was not interpreted as evidence of strict unidimensionality. The instrument and its structure were examined using the same 260 observations, providing preliminary, sample-specific psychometric evidence rather than independent validation. Replication in independent samples and other oasis settings, including measurement-invariance testing, remains necessary. Having established preliminary support for the three related dimensions, the analysis next examined how the global composite score varied with the prespecified farm and decision-maker characteristics.



3.3. Factors Associated with Perceived Resilience and Integrated Discussion

The regression was significant overall, robust Wald $\chi^2(10) = 41.61$, $p < 0.001$, but explained only 15.1% of score variance ($R^2 = 0.151$; adjusted $R^2 = 0.117$), leaving 84.9% unexplained. Variance inflation factors ranged from 1.03 to 2.84. The Breusch–Pagan test did not reject homoscedasticity at 5% ($p = 0.052$); HC3 standard errors had been selected a priori. Fourteen observations exceeded the exploratory Cook’s-distance threshold of $4/n$, with a maximum of 0.087. As shown in Table 5, education had the largest standardised coefficient among the measured variables ($B = 1.681$; $\beta = 0.272$; $p < 0.001$), although it was close to that of age ($\beta = 0.230$). Under the linear-trend assumption, one education-category increase corresponded to an adjusted 1.68-point score difference. Education may facilitate information access and learning, but these mechanisms were not measured (Darnhofer et al., 2016; Prat-Benhamou et al., 2024). Age was positively associated with the score ($B = 0.116$; $p = 0.004$), equivalent to approximately 1.16 points per ten-year difference. Accumulated experience, cohort differences, and survivorship of older decision-makers whose farms remain active offer competing interpretations that this cross-sectional design cannot distinguish. Neither coefficient establishes a causal effect or the effectiveness of educational or intergenerational interventions. Sex was not statistically associated with the score ($p = 0.774$), but the eight female respondents and wide confidence interval prevent a reliable assessment of gender differences. Selecting one main decision-maker may also underrepresent women’s informal economic contributions, unpaid work, and shared management responsibilities. These estimates therefore describe conditional farm-level associations, with substantial uncertainty about mechanisms and the dimensions of resilience omitted by the survey.

Table 5. Multiple linear regression of the overall perceived-resilience score ($N = 260$).

Variable	B	HC3 SE	β	95% CI	p
Constant	8.609	2.625	—	[3.439, 13.779]	0.001
Age	0.116	0.040	0.230	[0.037, 0.194]	0.004
Education	1.681	0.480	0.272	[0.736, 2.626]	< 0.001
Female decision-maker	−0.755	2.623	−0.026	[−5.920, 4.411]	0.774
Cultivated area	−0.157	0.347	−0.040	[−0.841, 0.527]	0.651
Crop diversification	−0.464	0.692	−0.042	[−1.826, 0.898]	0.503
Modernised irrigation	−0.305	1.009	−0.030	[−2.293, 1.683]	0.763
Agricultural training	1.597	0.899	0.159	[−0.173, 3.368]	0.077
Public support	−0.205	0.870	−0.020	[−1.917, 1.508]	0.814
Cooperative membership	1.529	0.771	0.149	[0.011, 3.048]	0.048
Climate-risk awareness	0.647	0.481	0.099	[−0.300, 1.594]	0.180

Note: The dependent variable was the overall perceived-resilience score, ranging from 9 to 45. B = unstandardised coefficient; HC3 SE = heteroscedasticity-consistent standard error; β = standardised coefficient; CI = confidence interval. For education and climate-risk awareness, B represents the estimated difference associated with a one-category increase under the linear-trend assumption. For binary variables, B represents the adjusted difference from the category coded 0. All tests were two-sided.

Cooperative membership showed a borderline positive association ($B = 1.529$; $p = 0.048$), but statistical support was not maintained in the binary and categorical sensitivity models; the hypothesised association was therefore not robustly supported. Membership measured affiliation, without assessing participation, benefit distribution, or organisational performance. Information exchange and peer learning remain plausible, untested pathways (Slijper et al., 2022). Agricultural training ($p = 0.077$), public support ($p = 0.814$), and climate-risk awareness ($p = 0.180$) showed no statistically established associations in the primary model. These findings do not demonstrate ineffectiveness, given the limited detail on training, support, and opportunities to translate awareness into action. Cultivated area, diversification, and modernised irrigation likewise had confidence intervals spanning zero; their negative estimates do not establish harmful associations. The binary diversification indicator omitted species composition and functional complementarity, limiting comparison with research on oasis agrodiversity (Houssni et al., 2023). For irrigation, M’Hamid research reports costly pumping and attachment to inherited land, with leasing or crop-sharing considered as alternatives (Sobczak-Szelc, 2024). Another local study describes uncertain groundwater availability and collective-well charges covering energy and maintenance, with allocation linked to historical water rights (Silva-Novoa Sanchez et al., 2025). Equipment usefulness could therefore depend on pumping and maintenance costs, effective water availability, land tenure, and secure access to land and water. These are possible mechanisms, not explanations established by this survey: land tenure was retained only descriptively, while costs, access security, water availability, and water governance were not directly measured. The unexplained variance cannot consequently be attributed to governance, nor can the findings establish collective oasis resilience. The following sensitivity analyses examine which associations persist across modelling choices and which depend on the specification.

3.4. Robustness and Sensitivity Analyses

Tables 6 and 7 summarises selected sensitivity estimates. The binary model contrasted 73 moderate with 187 low-resilience farms, providing approximately 7.3 events per predictor for ten predictors. Adjusted odds ratios may be imprecise, particularly for sparse



categories; this secondary analysis was not intended for prediction. The model was statistically significant overall, likelihood-ratio $\chi^2(10) = 40.16$, $p < 0.001$, with Nagelkerke's pseudo- $R^2 = 0.206$ and an apparent area under the receiver operating characteristic curve of 0.750. This describes within-sample discrimination, without external validation. Age and education retained positive associations, whereas cooperative membership was not statistically established ($OR = 1.855$; $p = 0.135$). Categorisation also reduces statistical information (Altman and Royston, 2006). Treating education and awareness categorically yielded $R^2 = 0.161$ and adjusted $R^2 = 0.117$. Compared with no formal education, primary ($B = 1.572$; $p = 0.038$) and secondary education ($B = 3.590$; $p < 0.001$) were positively associated, while higher education was imprecisely estimated ($B = 3.034$; $p = 0.557$; $n = 4$). Moderate awareness differed from low awareness ($B = 1.379$; $p = 0.040$), whereas high awareness did not ($B = 1.008$; $p = 0.321$); this isolated contrast does not establish non-linearity. Cooperative membership was marginal under this specification ($B = 1.488$; $p = 0.055$).

Table 6. Summary of robustness and sensitivity analyses (Panel A. Linear models with HC3 robust standard errors).

Variable	Model excluding influential observations B (p)	Activity maintenance B (p)	Unexpected-event management B (p)	Future anticipation B (p)
Age	0.101 (0.010)	0.034 (0.055)	0.037 (0.019)	0.046 (0.013)
Education	1.940 (< 0.001)	0.553 (0.012)	0.513 (0.007)	0.615 (0.005)
Female decision-maker	-0.709 (0.747)	-0.016 (0.989)	-0.804 (0.362)	0.065 (0.944)
Cultivated area	0.139 (0.624)	0.001 (0.997)	-0.053 (0.698)	-0.105 (0.413)
Crop diversification	-0.459 (0.470)	-0.301 (0.325)	-0.178 (0.485)	0.015 (0.960)
Modernised irrigation	-1.004 (0.279)	-0.076 (0.857)	0.096 (0.809)	-0.325 (0.497)
Agricultural training	1.731 (0.046)	0.538 (0.138)	0.382 (0.287)	0.677 (0.135)
Public support	-0.565 (0.505)	-0.133 (0.717)	-0.331 (0.301)	0.260 (0.528)
Cooperative membership	1.725 (0.014)	0.790 (0.022)	0.223 (0.440)	0.517 (0.148)
Climate-risk awareness	0.398 (0.372)	0.169 (0.408)	0.385 (0.040)	0.093 (0.667)

Table 7. Summary of robustness and sensitivity analyses (Panel B. Binary logistic model contrasting moderate with low perceived resilience).

Variable	Adjusted OR (p)	95% CI
Age	1.075 (0.001)	[1.029, 1.124]
Education	2.549 (< 0.001)	[1.543, 4.209]
Female decision-maker	0.964 (0.967)	[0.166, 5.611]
Cultivated area	0.989 (0.941)	[0.738, 1.326]
Crop diversification	0.686 (0.305)	[0.334, 1.409]
Modernised irrigation	0.918 (0.861)	[0.353, 2.387]
Agricultural training	1.297 (0.561)	[0.539, 3.121]
Public support	1.231 (0.595)	[0.572, 2.649]
Cooperative membership	1.855 (0.135)	[0.825, 4.168]
Climate-risk awareness	1.357 (0.223)	[0.830, 2.219]

Note: The model excluding 14 observations above the exploratory Cook's-distance threshold (4/n) included 246 farms; the dimension-specific and binary models included 260. Panel A reports unstandardised coefficients with HC3 inference; Panel B reports adjusted odds ratios with 95% confidence intervals. B = unstandardised linear coefficient; OR = odds ratio; CI = confidence interval; HC3 = heteroscedasticity-consistent covariance estimator, type 3. Two-sided p-values are reported in parentheses. Calculations are based on the survey data.

Excluding the 14 observations above the exploratory Cook's-distance threshold reduced the sample to 246 and increased R^2 from 0.151 to 0.193 (adjusted R^2 : 0.117 to 0.159). Age and education retained positive associations, while the cooperative coefficient increased from 1.529 ($p = 0.048$) to 1.725 ($p = 0.014$). Agricultural training became statistically significant ($B = 1.731$; $p = 0.046$), although it was not significant in the primary, binary, or dimension-specific models. Its statistical support was therefore specification-



dependent and exploratory. The full-sample model remained the primary analysis. Across dimensions, education was positively associated with activity maintenance, unexpected-event management, and future anticipation ($p = 0.012$, 0.007 , and 0.005 , respectively). Age was associated with unexpected-event management and future anticipation ($p = 0.019$ and 0.013), but not activity maintenance at the 5% threshold ($p = 0.055$). Cooperative membership was associated only with activity maintenance ($B = 0.790$; $p = 0.022$), and climate-risk awareness only with unexpected-event management ($B = 0.385$; $p = 0.040$). These isolated findings arose among multiple secondary tests and should remain exploratory. The modernised-irrigation $\times$ cooperative-membership interaction was not statistically established ($B = -2.279$; HC3 SE = 1.697 ; $p = 0.181$). R^2 increased only from 0.151 to 0.157 (adjusted R^2 : 0.117 to 0.120), and the estimate was imprecise, with only 12 farms using modernised irrigation without cooperative membership. Regressing the eight-item score without R4 yielded $R^2 = 0.152$: age ($B = 0.111$; $p = 0.004$) and education ($B = 1.553$; $p < 0.001$) remained positively associated, while cooperative membership was marginal ($B = 1.425$; $p = 0.054$). Overall, education and age were the most consistently supported associations; cooperative membership, training, and awareness depended on specification or dimension. No examined specification established an association with cultivated area, diversification, modernised irrigation, or public support. These sensitivity analyses clarify which associations were stable and which depended on modelling choices, thereby defining the empirical scope of the study.

3.5. Contribution, Scope, and Limitations of the Study

This study combines preliminary psychometric assessment with evidence on factors associated with perceived farm resilience in M'Hamid. Education and age showed the most consistent associations, whereas cooperative membership remained sensitive to model specification. The model left 84.9% of score variance unexplained, limiting claims about the relative importance of the measured factors. These associations do not establish causal effects or the effectiveness of particular interventions. Several limitations qualify these findings. The cross-sectional design precludes causal inference and cannot capture resilience trajectories before and after shocks. The score measures perceived capacity rather than observed post-shock performance. Because the same decision-maker reported predictors and resilience, perception, social-desirability, and common-method biases remain possible. The Harman diagnostic does not exclude common-method bias (Podsakoff et al., 2024). The 48% non-response rate and unavailable information on non-respondents prevent comparisons with respondents and leave potential selection bias unresolved. Generalisability is also limited by coverage of a single municipality and the absence of farms classified in the high-resilience category. Only eight female decision-makers participated, preventing reliable assessment of gender differences. Selecting one main decision-maker may additionally underrepresent women's informal economic contributions, unpaid work, and shared management responsibilities. All psychometric assessments of the new scale, including CFA, used the same 260 observations. Neither independent validation nor measurement-invariance testing was undertaken; both remain necessary. Moreover, the questionnaire did not directly measure water-allocation rules, participation, power relations, organisational performance, or conflict resolution. The explanatory role of these governance mechanisms therefore remains conjectural; unexplained variance cannot be attributed to them on the basis of this study (Darnhofer et al., 2016; Ostrom, 2009). Longitudinal and comparative studies combining farm surveys, interviews, hydrological data, and institutional analysis are needed to connect farm-level perceptions with collective oasis resilience.

4. Conclusion and Recommendations

This study examined the factors associated with farm-level perceived resilience among date-palm farms in M'Hamid El Ghizlane. Education and age showed positive adjusted associations, whereas cooperative membership was not robustly supported across specifications. The model explained only 15.1% of score variance. No statistically established associations were found in the primary model for cultivated area, diversification, modernised irrigation, public support, or climate-risk awareness. The education association supports evaluating locally adapted training; the age association suggests investigating intergenerational knowledge transfer. The uncertain cooperative association calls for examining organisational functioning and participation. The irrigation result does not justify recommending modernisation on the basis of this study, nor demonstrate its ineffectiveness. These recommendations identify avenues for evaluation rather than proven interventions. Potential links to the SDGs remain indirect and were not evaluated.

The cross-sectional design precludes causal inference, while the single-oasis setting, potential non-response bias, and perceptual outcome limit generalisability. Longitudinal and comparative studies integrating farm surveys, qualitative interviews, hydrological measurements, and institutional analysis are needed to examine how farm-level adaptive capacities relate to collective oasis resilience.

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Author Contributions

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