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Development and Validation of AgTech-Enabled Market Access Scale for Hi-Tech Agriculture

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HIGHLIGHTS

- A total of nine dimensions covering both traditional market access and emerging AgTech-driven aspects were identified for AgTech-enabled market access in hi-tech crop cultivation.
- The scale has high conformity (mean = 13.64), strong relevancy ratings (>3.0), high internal consistency (Cronbach' alpha value = 0.97), and significant dimensional distinctiveness (ANOVA, F = 3.301; p < 0.01

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ABSTRACT

Digital technologies and institutional innovations are increasingly shaping agricultural market access alongside traditional infrastructure. This study, conducted in 2025, developed and validated a multidimensional scale to systematically measure farmers' perceptions of AgTech-enabled market access in hi-tech cultivation. The validated scale consisted of 56 items across nine dimensions: transportation infrastructure, distance to market, market information access, digital market platforms, agri-input accessibility, market institutions, storage and logistics, intermediaries, and frequency of market visits. Empirical validation demonstrated high conformity (mean = 13.64), strong relevancy ratings (>3.0), high internal consistency (Cronbach' alpha value = 0.97), and significant dimensional distinctiveness (ANOVA, F = 3.301; p < 0.01). The mean value of Simpson's Index of Diversity was found to be 0.834, indicating the diverse nature of the scale items across the nine dimensions. The scale provides a robust and reliable instrument for researchers, policymakers, and extension professionals to assess AgTech-enabled market access, identify barriers, and design evidence-based interventions for strengthening hi-tech agriculture.

INTRODUCTION

Global agriculture is rapidly transforming through digitalization, automation, and data intelligence. Hi-tech agriculture integrates advanced technologies such as artificial intelligence (AI), robotics, sensors, Internet of Things (IoT), drones, and biotechnology to boost productivity, sustainability, and profitability (Bocean, 2024; Das et al., 2025). This transformation, driven by technology-enabled systems, plays a crucial role in enhancing market integration by connecting producers with buyers in real time. Traditionally, market access has been defined by spatial and infrastructural factors such as distance, transport, and reliance on intermediaries (Wang et al., 2025). However, farmers also face broader barriers, including information gaps, low bargaining power, poor logistics, and weak institutional linkages, which limit market efficiency and inclusiveness (Otekunrin, 2019; Barbier, 2023; Gurmu et al., 2024; Dey & Singh, 2025). In the AgTech era, market access now includes both physical and digital connectivity, which present previously unheard-of chances to revolutionize conventional farming methods (Chandra et al., 2024). Tools like real-time price information, e-

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NAM, blockchain traceability, and FPO-enabled trade networks have transformed how farmers access markets and ensure transparency (World Bank, 2019; Abiri et al., 2023; GOI, 2025). However, small and marginal farmers often face barriers such as cost, connectivity, digital literacy, and gender disparities, making AgTech both a market equalizer and divider (Choruma et al., 2024).

Despite the expanding body of research on agricultural digitalisation, there remains a major gap: the lack of a validated tool to systematically measure AgTech-enabled market access. Most studies focus on individual technologies rather than the integrated market access experience in the digital era (Jadhav, 2024; Janvry & Sadoulet, 2020). This limits comparative research, policy evaluation, and impact assessment across contexts. A scientifically validated measurement instrument is essential for quantifying latent constructs like farmers' perceived market accessibility. Therefore, the development of an AgTech-Enabled Market Access Scale (AEMAS) is both timely and necessary it allows for a standardized, quantifiable, and empirically valid assessment of farmers' perceptions toward market access in the digital agriculture ecosystem. AgTech-enabled market access includes physical, digital, and institutional domains, which together shape farmers' efficiency, profitability, and competitiveness. A validated scale capturing these dimensions enables systematic measurement and comparison, supporting evidence-based interventions for inclusive market integration.

Existing literature highlights gaps, including the lack of a framework integrating physical and digital market access and no validated scale to measure farmers' perceptions of AgTech-enabled markets. Accordingly, this study addresses two research questions: What are the core dimensions characterizing AgTech-enabled market access among hi-tech farmers, and how can these dimensions be systematically operationalized into a valid and reliable measurement scale? To this end, the proposed AEMAS is guided by two hypotheses: H_1–market access is a multidimensional construct encompassing physical, digital, and institutional domains, forming the conceptual basis of the scale; H_2–farmers' socio-economic characteristics significantly influence their perceived market access, supporting the scale's relevance and predictive capability. Developing a validated AEMAS addresses a key methodological and policy gap by quantifying farmers' market integration.

METHODOLOGY

A systematic procedure was employed to develop a scale for measuring AgTech-enabled market access in hi-tech agriculture, grounded in recognized methodologies for attitude and perception scale development (Edwards & Kilpatrick, 1948; Supe & Singh, 1976). The process comprised sequential stages to safeguard theoretical rigor and ensure empirical validity. Initially, a comprehensive pool of potential statements was generated, sourced from an extensive literature review and consultations with specialists in agricultural marketing, extension, and agri-business. These statements were intended to reflect diverse dimensions of market access and were provisionally associated with nine key conceptual domains, including transportation infrastructure, distance to market, market information access, digital market platforms, agri-input market accessibility, access to market institutions, storage and logistics, market intermediaries, and frequency of market visits.

Content validation formed the next stage and entailed expert consultations through Focus Group Discussions (FGDs). The primary objectives in this stage were to review each item for clarity, avoid duplication, and confirm representativeness and relevance. This thoroughly refined the item pool, ensuring statements were both precise and contextually appropriate. The third phase applied Edwards and Kilpatrick's (1948) informal criteria for attitude statements, emphasizing the exclusion of double-barreled items, universal qualifiers, and factual or binary forms. Focus was placed on clarity, singularity of idea, balance, precision, and discriminatory power. Each statement underwent systematic evaluation against 14 such criteria, with conformity scores guiding retention or modification.

Subsequently, a relevancy check was conducted, wherein experts rated the items using a four-point scale, ranging from "not relevant" to "highly relevant," further enhancing content validity and allowing for language refinement as required. Importantly, classification of items into the nine conceptual dimensions was reserved for the final stage, thereby minimizing the risk of classification bias. In the final stage, validated statements were systematically categorized under the nine dimensions, capturing both conventional aspects of market access and AgTech-driven components such as digital platforms and information flow. The diversity and representation across dimensions were evaluated using Simpson's Index of Diversity, calculated with the following formula:

$D = \Sigma(pi^2)$, where pi = Mean$i$ / Total mean

D = Simpson's Index, 1-D = Index of Diversity

One-way ANOVA was utilized to test for distinctiveness among items across dimensions. This comprehensive process resulted in a theoretically rigorous and empirically robust scale for evaluating AgTech-enabled market access in hi-tech agriculture.

RESULTS

Item Refinement and Finalisation

The scale development process produced a validated set of 56 statements, distributed across nine dimensions of AgTech-enabled market access. Initially, 110 items were generated; 52 were eliminated through expert review for duplication, ambiguity, or irrelevance of the content (Shitu et al., 2018; Gupta et al., 2022; Meethal & Thomas, 2024a; Kademani et al., 2025). Further application of Edwards and Kilpatrick's (1948) criteria ensured only statements meeting minimum conformity were retained, in line with established social science methodologies (Supe & Singh, 1976; Likert, 1932). The final 56 statements encompass both traditional (e.g., transportation, distance, intermediaries, institutions) and AgTech-driven (e.g., digital platforms, input access, market information) market access factors as shown in Table 1. This dual emphasis strengthens the instrument's ability to capture the evolving nature of agricultural markets in the digital era.

Conformity and Relevance Scores

The average conformity score for retained items was 13.64, indicating strong adherence to Edwards and Kilpatrick's criteria also eliminated ambiguous or irrelevant statements (Meethal & Thomas, 2024b). Most statements also scored above 3.0 on expert ratings

Table 1. Selected statements with conformity and mean score of AgTech enabled market access scale

S.No.	Statements	Conformity Score	Mean Score
I	Transportation Infrastructure		
1	The road to the nearest market is well-maintained with good quality.	14	3.397
2	The condition of rural roads enables the timely transportation of agricultural produce.	14	3.324
3	I face delays in transporting produce due to poor road infrastructure.	14	3.044
4	Seasonal changes (like rains) do not severely affect my road access to markets.	14	2.794
5	Transportation vehicles can access my farm without difficulty throughout the year.	14	3.162
6	My farm is connected to a paved road that allows vehicle access in most seasons.	13	3.103
7	The availability of local transport services supports my marketing activities.	14	3.162
8	I can access nearby towns using affordable transport options.	13	3.338
II	Distance to Market		
9	Market is within a convenient travel distance from my farm.	14	3.118
10	Distance does not significantly affect my frequency of visits to market.	14	2.794
11	I avoid some markets due to long travel distances.	14	3.044
12	I am satisfied with how quickly I can reach the main market from my farm.	13	3.221
13	The proximity to markets allows me to sell perishable items efficiently.	14	3.471
14	I can access more than one market within a short distance from my farm.	14	3.162
III	Market Information Access		
15	I receive real-time price updates through AgTech tools or mobile apps.	14	3.324
16	The absence of timely market information leads to poor sales decisions.	14	3.250
17	I use AgTech apps to access information about crop demand and supply.	13	3.059
18	I consider market demand and price trends when planning my crops.	13	3.206
19	The information I receive about markets helps me make better selling decisions.	14	3.176
20	I regularly use government or private SMS/IVRS for market updates.	14	3.015
21	I trust the accuracy of market information I receive through digital means.	13	2.809
IV	Digital Market Platforms		
22	I regularly use digital marketing platforms to sell my produce.	12	2.956
23	I feel digital platforms improve my market access and reduce dependence on middlemen.	13	3.250
24	I find registration in digital market platforms (eNAM, FPO, Kisan app) useful for selling my produce.	12	3.103
25	I find digital channels reliable for receiving payments after online sales	13	3.162
26	I face difficulty navigating digital market platforms.	14	3.368
27	Digital marketing tools have improved my access to distant buyers.	14	3.235
V	Agri-input Market Accessibility		
28	I receive timely information about input availability through AgTech tools.	14	3.088
29	Distance or availability does not hinder my access to essential inputs.	14	2.912
30	I have easy access to shops or cooperatives for buying quality agricultural inputs.	14	2.882
31	I find it easy to access shops that sell certified seeds, fertilizers, and inputs.	12	2.941
32	I receive updates on input availability through apps or helplines.	14	2.882
33	Delays in accessing quality inputs affect my crop planning.	14	2.897
34	Input dealers are located within a convenient distance from my farm.	14	2.882
35	I face no difficulty in obtaining credit or invoices from input providers.	14	2.691
VI	Access to Market Institutions		
36	I have access to regulated markets such as APMC or eNAM.	14	3.029
37	I am aware of the rules, pricing, and grading system in formal markets.	12	3.118
38	I find formal market procedures complex and time-consuming.	13	3.265
39	Farmer Producer Organizations (FPOs) help me with market linkages.	14	3.147
40	I prefer using government procurement schemes for selling my produce.	12	3.044
VII	Storage & Logistics		
41	I have access to cold storage or warehouses for short-term produce storage.	14	3.015
42	Lack of storage facilities forces me to sell produce immediately.	14	3.441
43	Transport logistics (vehicles, agents) are available when needed.	14	3.265
44	I use AgTech platforms to book logistics or manage supply chains.	14	3.015
45	Poor storage infrastructure increases my post-harvest losses.	14	3.206

Table 1 contd...

S.No.	Statements	Conformity Score	Mean Score
VIII	Market Intermediaries		
46	I rely on middlemen for selling my produce.	14	3.103
47	I sell my produce directly to traders or commission agents.	14	3.191
48	I rely on middlemen because they offer timely payment and pickup.	13	3.162
49	Middlemen reduce my profit margins significantly.	14	3.206
50	I prefer using digital tools to bypass intermediaries.	14	3.368
51	I have bargaining power over the prices offered by intermediaries.	14	3.088
IX	Frequency of Market Visits		
52	I visit the market more than once a week during the harvest period.	14	2.956
53	I make fewer market visits due to availability of digital sale channels.	14	3.015
54	High transportation cost reduces my frequency of market visits.	14	3.088
55	Regular market visits help me build relationships with buyers.	14	3.206
56	I coordinate marketing decisions based on scheduled market days.	14	3.176

for relevance, supporting both content and face validity. This reflects items' conceptual soundness, clarity, relevance to the construct measured and ensuring that the instrument is scientifically robust and practically meaningful (DeVellis, 2017).

Reliability of the Scale

Reliability refers to the consistency and stability of a measurement instrument (Raj & Thomas, 2022). A reliable scale consistently yields similar results when measuring the same construct under comparable conditions. In this study, reliability was assessed using Cronbach's Alpha, a widely recognized statistical measure for evaluating internal consistency in multi-item scales (Ray & Mondal, 2011; Collins, 1996). Cronbach's alpha was calculated for the 56-item AgTech-enabled Market Access Scale based on responses from 68 experts, using the formula:

$$\alpha = (N / (N - 1)) \times [1 - (\Sigma\sigma_i^2 / \sigma T^2)]$$
$$\alpha = (56 / (56 - 1)) \times [1 - (53.66 /1040.52)] = 0.9657$$

Where, N = Number of items in the scale = 56, σ_i^2 = Variance of each individual item (i = 1 to N)
$\Sigma\sigma_i^2$ = Sum of the variances of all items = 53.66, σT^2 = Variance of the total score (sum of all items for each respondent) =1040.52

The computed Cronbach's alpha value of 0.97 demonstrates excellent internal consistency, confirming that the scale items are coherent and reliable for assessing AgTech-enabled market access in hi-tech agriculture. Additionally, dimension-wise Cronbach's alpha values ranged from 0.72 to 0.87, further indicating high internal consistency within each dimension, as presented in Table 2. While these high values confirm the constructs' coherence, they may also suggest redundancy, implying that item reduction could be considered in future refinements.

Validity of Scale

Validity reflects how accurately an instrument measures the intended construct, making it essential for drawing meaningful, relevant, and practical conclusions in studies of AgTech-enabled market access (Singh, 2019). The distribution of 56 statements across nine dimensions demonstrates that the scale effectively captures the complex and multifaceted nature of market access in hi-tech agriculture. Some dimensions, such as transportation infrastructure and agri-input market accessibility, include more items, while dimensions like access to institutions and frequency of market visits have fewer items. This distribution is both intentional and methodologically sound, as items were classified into dimensions only after the elimination process to prevent bias during selection.

Dimensional Representation

To assess the representativeness of each dimension, Simpson's Index of Diversity (1–D) was calculated, yielding values from 0.800

Table 2. Dimension-wise reliability, Simpson'D and Simpson's Index of Diversity (1 - D)

Dimension	No. of Items	Cronbach's Alpha (α)	Simpson'D	Simpson's Index of Diversity (1 – D)
Transportation Infrastructure	8	0.8576	0.1249	0.875
Distance to Market	6	0.7191	0.1670	0.833
Market Information Access	7	0.8514	0.1429	0.857
Digital Market Platforms	6	0.8745	0.1665	0.834
Agri-input Accessibility	8	0.8742	0.1247	0.875
Market Institutions	5	0.8574	0.1998	0.800
Storage & Logistics	5	0.7958	0.2000	0.800
Market Intermediaries	6	0.8305	0.1664	0.834
Frequency of Market Visits	5	0.7574	0.1998	0.800
				Mean = 0.834

Table 3. Summary of ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.586	8.000	0.073	3.301	0.006	2.194
Within Groups	0.844	38.000	0.022			
Total	1.430	46.000				

to 0.875 and an overall mean of 0.834, as shown in Table 2. These consistently high values indicate that the scale maintains strong dimensional diversity and avoids over-concentration in any single category. Such diversity is crucial, ensuring that the scale holistically assesses market access without disproportionate emphasis on particular components.

Distinctiveness Across Dimensions

A one-way ANOVA conducted on the mean scores across dimensions revealed significant variation ($F = 3.301$; $p < 0.01$).

Maximum mean score – F crit = 3.471-2.194 = 1.277

It is evident that no mean score across dimensions falls below this threshold. This suggests that the mean scores for all dimensions are comparable. The calculated F-statistic exceeding the F-critical value confirms a statistically significant difference among the dimensions (Kim, 2014). This finding provides strong evidence that the dimensions are not redundant but represent distinct constructs within the broader concept of market access. These results align with previous research emphasizing the increasing complexity of agricultural market systems, where traditional and digital elements coexist and collectively influence farmers' market access and decision-making processes (Choruma et al., 2024).

DISCUSSION

The scale was developed and validated to measure AgTech-enabled market access in hi-tech agriculture, following established procedures in social science research. The final instrument consists of 56 statements spanning nine dimensions, ensuring coverage of both traditional market access factors and new AgTech-driven components. By incorporating input from subject matter experts and adhering to rigorous criteria for item construction, the scale achieves both content and conceptual validity. High conformity and relevance scores indicate that the retained items are clear, unbiased, and directly related to the construct being measured. Reliability analysis yielded a strong overall Cronbach's alpha of 0.97, with dimension-wise coefficients between 0.72 and 0.87. These values confirm that the scale and its dimensions consistently assess coherent aspects of market access, though future refinement may address potential item redundancy.

Dimensional validity was supported by the distribution of statements and Simpson's Index of Diversity values, which ranged from 0.800 to 0.875. This demonstrates a balanced representation across all dimensions, minimizing over-concentration and ensuring that the scale holistically evaluates market access. Results from the one-way ANOVA revealed significant differences among dimensions, as indicated by an F-statistic greater than the critical value. This establishes that each dimension captures a distinct facet of market access, rather than duplicating information. Such differentiation is essential for understanding how both traditional and digital factors affect farmers' ability to access markets.

Overall, the AgTech-enabled market access scale offers a scientifically robust tool for research and extension work. It provides reliable and comprehensive measurement of market access in hi-tech agriculture, supporting future studies and policy interventions targeting both technological advancements and persistent structural barriers. The validated AgTech-enabled Market Access Scale offers multiple contributions for researcher, policymakers and extension systems to do research and practice. It provides a standardized, multidimensional scale to identify bottlenecks in AgTech adoption and supports the design of targeted capacity-building programs that address both traditional and digital challenges.

CONCLUSION

A systematic scale development procedure led to the construction of a validated 56-item AgTech-enabled Market Access Scale covering nine dimensions of hi-tech agriculture. The iterative refinement through expert consultation and relevancy testing ensured methodological rigour and content validity. Statistical checks, including conformity scores, relevancy ratings, and ANOVA, confirmed both robustness and dimensional distinctiveness. The scale empirically integrates traditional aspects of market access with emerging digital and institutional factors, providing a reliable tool for assessing farmers' perceptions. It holds practical value for researchers, policymakers, and extension systems in measuring adoption barriers, designing interventions, and strengthening market linkages in the AgTech era.

DECLARATIONS

Ethics approval and informed consent: Informed consent was sought from the experts possessing specialized knowledge in animal husbandry, dairy science, and extension education to obtain validation. Based on the experts' feedback, a pilot study was conducted with 60 randomly selected dairy farmers from non-sampling villages.

Conflict of interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declare that during the preparation of this work, they thoroughly reviewed, revised, and edited the content as needed. The authors take full responsibility for the final content of this publication.

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