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Empowering tribal women through skill-based fennel processing training: a pathway to sustainable socio-economic development in Sirohi, Rajasthan

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Primary processing of fennel (*Foeniculum vulgare*) in the Sirohi district of Rajasthan is mainly carried out by tribal women, who are a vital but under-supported part of the local agri-value chain. Despite their important role, there is significant potential to increase their income through focused capacity-building and better access to suitable technologies. To address this, the Krishi Vigyan Kendra, Sirohi, implemented a structured series of skill-focused training programs over 8 years (2008–2016), including one-day, three-day, and seven-day sessions during the cropping season. A total of 500 tribal women, organized into small groups of 25–30 participants, received hands-on, practical training. The training emphasized scientifically relevant aspects of fennel primary processing, such as optimized harvesting of umbels at the post-mature stage, standardized grading into A to C categories, and improved drying using modified shade houses built with local materials to preserve the green color and volatile compounds. It also covered hygienic threshing and packaging using polythene-lined bags to maintain qualities like texture, aroma, and market shelf-life. Results show that the training greatly improved processing efficiency and the adoption of better practices, leading to the transformation of nearly 70% (3,888 ha) of fennel-growing areas into primary processing operations up to 2024–25. Economic analysis estimates an additional return of ₹ 42.94 crores at the district level. The trained women reported higher daily earnings (₹ 500–750) compared to unskilled workers (₹ 250–300), highlighting the positive impact of skill development on wage differences. Overall, the intervention significantly increased household income, improved livelihood security, and raised the socio-economic status of rural and tribal women. These findings emphasize the importance of skill development and decentralized primary processing as effective strategies to strengthen rural value chains and promote women's economic empowerment in marginalized regions.

KEYWORDS

agri-value-chain, household income, livelihood, primary processing, self-employment

Introduction

Agriculture continues to serve as the backbone of India's rural economy, supporting the livelihoods of a majority of the population and shaping socio-economic development across diverse regions (NITI Aayog, 2021). India is globally recognized as the leading producer and consumer of spices, which not only contribute significantly to national income and export

earnings but also play an essential role in crop diversification, nutritional enhancement, and livelihood security for smallholder farmers (Singh and Meena, 2022; Spices Board India, 2023). In the semi-arid landscapes of Rajasthan, particularly in Sirohi district, recent shifts in cropping patterns reflect an increasing preference for high-value spice crops such as fennel (*Foeniculum vulgare*), driven by their strong market demand, climate resilience, and potential to improve household incomes among rural and tribal communities (Kumar et al., 2021; Choudhary et al., 2022). Fennel, traditionally cultivated as a Rabi crop, has adapted well to local agro-climatic conditions that allow its cultivation during the Kharif season in parts of southwestern Rajasthan. Sirohi district significantly contributes to the state's fennel acreage and production, emerging as a key cluster for fennel-based livelihood activities (Department of Agriculture, Rajasthan, 2022). Despite its economic potential, small and tribal farmers often receive low prices because of limited knowledge of scientific primary processing techniques such as stage-specific harvesting, hygienic drying, efficient threshing, mechanical grading, and moisture-controlled packaging (Bhardwaj et al., 2013; Sharma et al., 2020). Poorly processed fennel not only suffers quality degradation but also fails to meet market standards, leading to lower price realizations (Bhardwaj et al., 2013). Conversely, adopting improved processing technologies has been shown to increase farmers' income two to three times, highlighting substantial untapped potential for value addition at the village level (Mehta and Rathore, 2023). Tribal women farmers play a central role in the primary processing of fennel, contributing significantly to both household subsistence and local spice value chains (Bhardwaj et al., 2014). Their work encompasses critical post-harvest operations, such as threshing, winnowing, cleaning, drying, sorting, and grading, which directly affect the purity, aroma retention, and commercial grade of fennel seeds. These operations align with environmentally sustainable practices and require minimal external inputs. Given the rising market demand for naturally processed spices, recognizing and supporting the contributions of tribal women becomes essential for improving rural livelihoods, strengthening supply chains, and sustaining indigenous agricultural knowledge. Recognizing these challenges, Krishi Vigyan Kendra (KVK) Sirohi has developed an integrated primary processing package that addresses critical gaps in farmers' knowledge and skills. The KVK delivers structured, need-based, skill-oriented training programs, including three and seven-day residential courses and one or two-day field-based demonstrations designed to strengthen farmers' understanding of fennel processing and market-linked quality standards. Training sessions are strategically conducted during the harvesting (December–February) and processing (March–May) seasons and combine theoretical instruction with intensive hands-on demonstrations facilitated by multidisciplinary experts from universities, spice research centers, agro-industries, and progressive farmers networks. The modules emphasize practical competencies such as timing of umbel harvest, scientific drying techniques, quality grading, hygienic packing, and marketing strategies. A major focus of the initiative is the empowerment of tribal women, who play a crucial yet often undervalued role in the post-harvest segments of agricultural value chains (FAO, 2023). This study provides specialized skill-oriented training of 1–7 days to groups of 25–30 tribal women, covering 500 beneficiaries across key fennel-growing villages in Sirohi. Exposure to skill-based training has significantly strengthened their technical capabilities, enhanced their participation in local value addition, and enabled them to establish micro-enterprises that generate reliable supplementary income (Rathod and Patel, 2021). Women's collectivization through farmer groups and self-help organizations further accelerates technology adoption, market access, and enterprise sustainability, as

these institutions foster knowledge exchange, financial inclusion, and shared risk (Patel et al., 2022). Positioned as a pivotal extension institution under the Indian Council of Agricultural Research (ICAR), KVK Sirohi serves as a crucial interface between research and field-level application (Bhardwaj et al., 2013). Through continual training, technology refinement, and participatory approaches, the KVK plays an instrumental role in promoting sustainable agricultural development, enhancing farm productivity, and improving income security among rural and tribal households.

Materials and methods

The study was carried out from 2008 to 2024 in the operational villages of Krishi Vigyan Kendra (KVK), Sirohi, Rajasthan, to assess the impact of training of fennel (*Foeniculum vulgare*) primary processing technologies on the socio-economic development of tribal women. The study adopted a quasi-experimental, longitudinal impact evaluation design to assess the long-term socio-economic effects of skill-oriented training on primary processing of fennel.

Study area and target group: The investigation was initiated in 2008 across five KVK-adopted, fennel-producing tribal villages (Kacholi, Phoola Bai ka Khera, Nagpura, Sanwara, and Panchdeval) of the district Sirohi (Rajasthan). The target population consisted of tribal farm women involved in fennel cultivation and post-harvest activities. Skill-oriented training programs were continually organized from 2008 to 2016 during the cropping season of fennel (December to May). Two respondent categories were identified: Trained group (women who received formal KVK skill-oriented training on fennel primary processing) and Untrained group (women engaged in fennel cultivation but practicing unprocessed or partially processed methods without training). This grouping allowed a comparative evaluation of adoption, income change, and technology utilization following extension interventions (Rogers, 2003).

Sampling design and selection of respondents: A purposive sampling technique was applied to select villages and respondents, following standard procedures for impact evaluation in a rural setting (Cochran and Cox, 1950; Kothari, 2004). From each selected village, 50 tribal women (25 trained + 25 untrained) were sampled, yielding a total sample size of 250 respondents (125 trained and 125 untrained). Equal allocation ensured balanced representation and minimized sampling bias. A quasi-experimental research design involving a comparison between trained and untrained respondents was adopted, which is considered appropriate for technology impact assessment in agricultural extension research (Creswell, 2014; Bernard, 2017).

Development and pre-testing of research instrument: A structured questionnaire was developed based on earlier studies on technology adoption and post-harvest practices (Sanyang et al., 2009; FAO, 2013). The instrument was pre-tested with a pilot group to assess clarity, content validity, and cultural appropriateness. Modifications were incorporated based on respondent feedback and expert consultation. The questionnaire included predominantly closed-ended items, covering variables such as demographic profile, awareness and adoption of primary processing technologies, labor utilization and employment generation, yield and market price realization, post-training income changes, and constraints in processing and marketing. Although the questionnaire was prepared in English, interviews were conducted in Hindi and the local dialect (Marwari) to ensure comprehension and avoid interviewer bias.

Data collection and statistical analysis: The skill-oriented training intervention on primary processing of fennel was conducted during the period 2008–2016; the study was intentionally designed to assess the long-term and sustained socio-economic impact of these training activities. Primary data were therefore collected continuously and periodically from 2008 to 2024 through personal interviews conducted at respondents' homes, farms, Gram Sabha meetings, and on-field processing sites, following standard survey and impact assessment procedures (Bhardwaj et al., 2014). The post 2016 data (2016, 2020, and 2024) represent follow-up observations on the same respondent groups to capture the durability, adoption continuity, and cumulative effects of the training over time. The post-training impacts were observed periodically from 2008 to 2024 through structured and semi-structured personal interviews from an untrained group (2012) served as a baseline comparator, while trained respondents were assessed at multiple post-intervention points (2016, 2020, and 2024). Socio-economic variables were observed using a mixed-method approach, combining structural quantitative indicators with qualitative assessments, followed by standard practices in extension research and livelihood impact evaluation. Data were collected through personal interviews, field observation, and participatory interactions using pre-tested schedules to ensure reliability and comparability across respondents and time periods (Babbie, 2013; FAO, 2018). Interviews were carried out with the assistance of village-level workers to facilitate trust and accurate responses. Laborers involved in fennel processing were interviewed in real-time to capture reliable employment and labor distribution data. Secondary information was collected from published and unpublished records of KVK Sirohi, government reports, progressive farmers' labor registers, and relevant scientific literature. The potential market rate of fennel for the experimental period 2008–2024 was collected from Krishi Upaj Mandi, Summerpur-Pali (Rajasthan) records and official agricultural statistics, Government of Rajasthan (Department of Agriculture, Rajasthan, 2022). Following field data collection, responses were coded and transferred to tally sheets for systematic tabulation (Kothari, 2004). Descriptive statistics, including means, frequencies, and percentages, were used to analyze socio-economic indicators and adoption patterns. To quantify the effectiveness of fennel primary processing technologies, the technology gap, extension gap, and technology index were computed using the established formulas of Samui et al. (2000). The technology gap was calculated as the difference between the potential market rate of fennel and the market rate of primary processed fennel. The extension gap was calculated as the difference between the market rate of primary processed fennel and the market rate received by untrained farmers for their produce.

$$\text{Technology Index} = \frac{\text{Potential Market Rate} - \text{Primary Processed Market Rate}}{\text{Potential Market Rate}} \times 100$$

Results and discussion

Involvement of tribal women in primary processing activities

Tribal women play an essential role in the primary processing of fennel in the study villages. Field survey data show that women are

actively involved in nearly every stage of the post-harvest value chain (Table 1). Their participation from 2008 to 2016 and 2016–2024 shows high in tasks such as timely harvesting of fennel umbels (93 and 94%), collecting and transporting umbels from the field to drying structures (91 and 89%), grading umbels before drying (95 and 98%), and collecting dried umbels for threshing (96%), respectively. They also significantly contribute to labor-intensive tasks like threshing (85 and 90%), winnowing (95 and 98%), debris removal (98%), and final seed cleaning (100%). Additionally, many women participate in constructing drying structures (76 and 70%), arranging umbels during drying (64 and 83%), quality grading of fennel seeds (92 and 95%), and packaging the final product (73 and 60%). The analysis of tribal farm women's contribution to the primary processing of fennel from 2008 to 2016 and 2016–2024 shows that women consistently perform most post-harvest activities, with overall participation slightly rising from 88.16 to 89.25%. Their dominance is especially evident in tasks requiring precision and sustained effort, such as cleaning, grading, winnowing, and debris removal, where female participation remains between 95 and 100%. The most notable increase over time occurs in arranging umbels in drying structures (+0.30), emphasizing that this delicate and quality-critical task continues to rely heavily on women's skills. Conversely, activities like constructing drying structures, transporting umbels, and packing show a decrease in female participation, indicating a shift toward male involvement in more physically demanding tasks. These findings reflect a persistent gender-based division of labor in tribal farming systems, consistent with earlier research indicating that rural and tribal women carry out most post-harvest responsibilities in spice and seed production (Bhardwaj et al., 2014; Patel and Prajapati, 2018; Singh and Kaur, 2017). However, the high involvement of women in manual, labor-intensive tasks highlights the necessity for targeted interventions, such as drudgery-reducing tools, training, and institutional support, to improve efficiency and fairness across the fennel value chain. The findings confirm earlier research emphasizing the critical role of rural and tribal women in primary processing and value-added activities. Farouque and Anwar (1998) reported that women's education, technical knowledge, extension contact, and attitudes toward technology greatly influence their engagement in self-employment and household-based agricultural tasks. Similar observations were made by Bhardwaj et al. (2014), Nandal and Ojha (2012), noting that fennel primary processing activities in Rajasthan are predominantly performed by women, especially those from tribal communities. Recent studies further corroborate these findings that the strong participation of rural women in spice value chains and post-harvest operations (Bera and Roy, 2020), tribal women acquire significant skills in spice cleaning, drying, and grading (Choudhary et al., 2022), farm women in India significantly contribute to post-harvest operations such as threshing, cleaning, and storage (Bojjagani et al., 2025), and women lead value-added enterprises based on traditional crops (Naveen et al., 2023; Pandey et al., 2024). Mehta and Rathore (2023) confirmed that women remain the main contributors to labor-intensive post-harvest processes in smallholder spice enterprises. Moreover, FAO (2023) and Patel et al. (2022) stressed that women's involvement in agricultural value chains is essential for strengthening rural livelihoods, improving product quality, and sustaining local agro-based industries. Gupta et al. (2024) recorded active women's participation in multiple post-harvest tasks, including drying, cleaning, and sorting, underscoring the critical role of women in post-harvest management. Collectively, these studies demonstrate that tribal women continue to play a vital role in

TABLE 1 Contribution of tribal farm women in the primary processing of fennel.

Various primary processing activities	Involvement in Per cent				
	Mean of 2008–2016		Mean 2016–2024		% change in female participation
	Male	Female	Male	Female	
Timely harvesting of fennel umbels	7	93	6	94	0.01
Construction of a drying structure for umbel	24	76	30	70	−0.08
Collection and transportation of umbel from the field to the drying structure	9	91	11	89	−0.02
Grading of umbels before drying	5	95	2	98	0.03
Arrangement of the umbel in the drying structure	36	64	17	83	0.30
Collection of umbels after drying for threshing	4	96	4	96	0.00
Threshing of umbels	15	85	10	90	0.06
Removal of debris from fennel seeds	2	98	2	98	0.00
Winnowing of seeds	5	95	2	98	0.03
Cleaning of seeds	0	100	0	100	0.00
Grading of seeds	8	92	5	95	0.03
Packing of seeds	27	73	40	60	−0.18
Total share in primary processing	11.84	88.16	10.75	89.25	0.01

sustaining and enhancing the fennel value chain through their extensive and skilled contributions to post-harvest operations (Table 2).

Contribution of tribal women to the incremental returns of the district

Primary processing significantly improves the quality, grade specification, and market competitiveness of fennel, thereby measurably contributing to the regional economy. Tribal women play a key role in these value-adding activities by performing a series of scientifically structured post-harvest tasks, including harvesting umbels at the optimal post-maturity stage; executing multi-stage grading to remove undersized, infested, discolored, or lightweight seeds; eliminating inert matter through sieving; and using locally developed thresher-cum-grader units to achieve uniform seed size and purity. The economic contribution of tribal farm women in Sirohi district through primary fennel processing is substantial, yielding both direct financial benefits and broader livelihood impacts. Grading fennel into quality categories (A, B, and C) resulted in different earnings, with Grade A produce earning the highest of ₹257,000 per hectare due to its premium market rate of ₹210–250 per kg and a 59–65% share in total produce, followed by Grade B (₹57,000/ha) and Grade C (₹24,000/ha), culminating in total earnings of ₹338,000 per hectare. A comparison between graded (₹187.70/kg) and ungraded (₹125/kg) fennel showed a significant income difference of ₹113,000 per hectare, mainly due to

primary processing activities like grading, in which tribal women participate at an 89.25% rate. Approximately 3,800 hectares adopting primary processing, the total additional income in Sirohi district amounts to ₹429,400,000, with women's contributions estimated at ₹382,166,000, highlighting their vital role in value addition and rural economic growth. The technology gap and extension gap were 1.12, and the technology index of 24.92% was reported, further pointing to the potential for improving scientific grading and post-harvest practices to maximize income. These findings support earlier reports (Sagar and Chandra, 2004; Ahmad et al., 2007; Jamali, 2009; Nandal and Ojha, 2012; Bhardwaj et al., 2014) emphasizing the crucial socio-economic role of rural and tribal women in post-harvest operations and value addition, and reinforce that skill-based training significantly enhances product quality, market value, and technology adoption among farm women. Recent research further shows that women's participation in spice value chains notably boosts product quality, household income, local resilience, rural employment, and empowerment (Acharya and Basu, 2020; Bera and Roy, 2020; Mehta and Rathore, 2023; Patel and Prajapati, 2018; Sharma et al., 2020; Rathod and Patel, 2021). The evidence also confirms that structured processing and grading systems can raise producer prices and strengthen local economies, especially when women form the backbone of agricultural labor (Singh and Kaur, 2017). Overall, this data demonstrates that tribal women's active participation in the primary processing of fennel enhances product quality and market value and acts as a key driver of

TABLE 2 Contribution of tribal farm women in the incremental returns of district Sirohi through primary processing of fennel.

S.N.	Grade	Rate Rs per kg	Percent produce	Earning per ha (₹)
1	A	210–250	59–65	257,000
	B	135–155	19–25	57,000
	C	75–90	13–19	24,000
	Total			338,000
2	Graded	187.70	18	338,000
3	Ungraded	125.00	18	225,000
Difference in income due to secondary agriculture per ha.				113,000
Total area under the adoption of primary processing				3,800 ha
Total additional income due to primary processing in district Sirohi (113,000 × 3,800 ha = ₹ 429,400,000)				429,400,000
Present role of tribal women in primary processing				89.25%
Economic empowerment of tribal women through primary processing of the fennel in the district of Sirohi				382,166,000
Technology gap (₹/ha) = $250 - 187.7 = 62.30 \times 1,800$ kg (Yield/ha) = ₹ 112,140				1.12
Extension gap (₹/ha) = $187.70 - 125.0 = 62.70 \times 1,800$ kg (Yield/ha) = ₹ 112,860				1.12
Technology index = $(250 - 187.7) / 250 \times 100 = 22.94$				24.92%

economic uplift in Sirohi district. Collectively, the findings highlight that skill-based training and technology adoption by tribal women are essential for economic empowerment and sustainable development in spice-growing regions.

Impact on the socio-economic status of tribal farm women

The socio-economic analysis of the respondent groups revealed that the adoption of primary processing practices in fennel production has had a substantial positive impact on household wellbeing, income levels, and overall livelihood security (Table 3). The trained group demonstrated a remarkable increase in average annual income, rising from ₹275,000 in 2012 to ₹565,000 in 2024, compared with only ₹132,000 among the untrained group, indicating the significant financial advantage associated with skill development in post-harvest handling. Consistent employment generation (270 man-days/ha) further underscores the stabilizing effects of primary processing on labor availability. Improvements in living standards were evident through higher rates of pucca house construction (increasing from 35 to 68% between 2012 and 2024) and access to household utilities, which rose from 42 to 85% during the same period. Financial inclusion also improved substantially among trained respondents, with bank accounts holding more than ₹10,000 increasing from 15% in the untrained group to 92% by 2024. Social indicators showed parallel improvements in children's enrolment in better English medium schools, which rose to 45%, interaction with extension workers increased to 92%, and ownership of personal transportation grew dramatically from 18% in the untrained group to 95% by 2024. Enhanced awareness of health and hygiene, improved agricultural implement use, and increased participation in social work further reflected

socio-cultural upliftment. Importantly, women's participation in decision-making improved from 13% in the untrained group to 52% among trained households, demonstrating the empowerment potential of skills-based agricultural interventions. The involvement of tribal women in primary fennel processing also strengthens social and economic empowerment. Enhanced participation in spice value chains increases women's decision-making power within household and community groups, fosters leadership in self-help groups, and creates opportunities for micro-enterprise development (Kabeer, 2005). Skilled tribal women involved in primary processing are key to improving the socio-economic status of a community, and they were getting ₹ 200–250 day⁻¹ for harvesting and primary processing of fennel, whereas other unskilled women were getting only ₹ 100–150 day⁻¹ (Bhardwaj et al., 2014). These findings align with earlier research showing that training in post-harvest technologies enhances farm income, resource access, and household welfare (FAO, 2011; Bhardwaj et al., 2014; World Bank, 2014; Singh and Kaur, 2017), and corroborate evidence that value addition and primary processing significantly contribute to socio-economic empowerment in tribal communities (Acharya and Basu, 2020; Patel and Prajapati, 2018). The increased earnings have contributed to improved household decision-making, strengthened socio-economic independence, and broadened opportunities for rural entrepreneurship among tribal women (Bera and Roy, 2020; Choudhary et al., 2022). These outcomes resonate with Naveen et al. (2023) documented that tribal women's entrepreneurship dramatically increased their asset ownership, social status, and decision-making power. Overall, the adoption of primary processing technologies has yielded multifaceted socio-economic benefits, supporting the broader argument that capacity-building interventions can substantially improve the livelihoods of smallholder and tribal farming households.

Impact on tribal women's knowledge level and technology adoption

The results clearly demonstrate that training interventions had a significant and positive impact on the knowledge levels of respondents regarding the primary processing of fennel (Table 4). Across all activities, knowledge scores increased substantially after training with an overall mean gain of 47%, indicating the effectiveness of the capacity-building program. The greatest improvement was observed in the areas of collection and transportation of umbels (71%), cleaning of seeds (58%), winnowing (56%), grading of umbels (60%), and collection of dried umbels for threshing (50%), reflecting the crucial role of skill-oriented training in enhancing understanding of key post-harvest operations. Even activities where respondents had relatively higher initial familiarity, such as the construction of drying structures (47–82%) and arrangement of umbels in drying structures (40–69%), showed considerable gains of 35 and 29%, respectively, demonstrating that structured training effectively strengthened existing knowledge (Table 4). These findings align with earlier research indicating that training and exposure to improved post-harvest technologies significantly boost farmers' knowledge, efficiency, and adoption of scientific processing methods (FAO, 2011; Bhardwaj et al., 2014; Singh and Kaur, 2017). The notable improvement in tasks requiring technical precision, such as grading, cleaning, and winnowing, supports previous evidence that women and small-scale farmers greatly benefit from hands-on learning approaches in spice processing and value addition (Patel and Prajapati, 2018; Acharya and Basu, 2020).

TABLE 3 Socio-economic impact of primary processing of fennel on respondent groups.

Essential components	Respondents (n = 250)				
	Non-primary processing (Untrained group)	Adopt primary processing (Trained group)			
		2012	2016	2020	2024
Average annual income (₹)	132,000	275,000	325,000	417,000	565,000
Employment generation (man-days/ha)	228	270	270	270	270
Construction of a pucca house	15.0	35.0	42	53	68
Utility facilities (Radio, TV, CD player, bed, storage bin, etc.)	17	42	53	72	85
Bank account with more than ₹ 10,000 balances	15	42	76	85	92
Children's education in a good school	11	23	32	39	45
Improved agricultural implements	17	36	39	45	52
Interaction with extension workers for different field problems	42	72	80	84	92
Personal transportation facilities (cycle, motorcycle, car)	18	53	60	72	95
Adoption of new technology	15	35	41	47	50
Understanding of urban society	10	17	22	32	40
Awareness about health and hygiene	19	20	28	33	35
Participation in social work	19	29	35	39	42
Change in behavior and thought	11	22	28	36	45
Telephone and Mobile facilities	33	47	67	87	100
Women's participation in decision-making	13	32	38	47	52

The assessment of knowledge levels among farm women before and after training on primary processing of fennel revealed a substantial improvement attributable to the intervention. Before training, the majority of participants (65%) fell within the low knowledge category, while only 15% demonstrated high knowledge (Table 5). Following the training program, the proportion of women in the low category declined sharply to 17%, representing a 73.84% reduction, indicating a significant shift away from low baseline awareness. Concurrently, the medium knowledge category increased from 20 to 52%, marking a 160% improvement, while the high knowledge category more than doubled from 15 to 31%, reflecting a 106% increase (Table 5). These results highlight the effectiveness of structured, hands-on training in elevating the technical competence of tribal and rural women in post-harvest processing activities. Similar trends have been reported in previous studies, where capacity-building interventions have led to significant advancements in knowledge acquisition, the adoption of improved practices, and the empowerment of women in agricultural value chains (Singh and Kaur, 2017). The marked shift toward medium and high knowledge levels is consistent with findings by Patel and Prajapati (2018), who emphasized that targeted training on seed spice processing significantly enhances both theoretical understanding and

practical skills among women farmers. The analysis of the adoption levels of farm women before and after training on primary processing of fennel demonstrated a marked improvement attributable to the intervention (Table 6). Before training, a large majority of respondents (73%) were concentrated in the low adoption category, reflecting limited use of recommended primary processing practices. After the training program, this proportion declined substantially to 40%, representing a 45.2% reduction, and indicating that many women transitioned out of the lowest adoption tier. Correspondingly, the medium adoption category increased dramatically from 18 to 46%, showing a 155.5% rise, which highlights the effectiveness of training in promoting partial or full adoption of improved practices. Similarly, the proportion of women in the high adoption category increased from 9 to 14%, reflecting a 55.5% enhancement in the uptake of recommended technologies and post-harvest operations. Overall, the data suggest that the training intervention significantly improved the adoption behavior of farm women, shifting them from low to medium and high adoption categories, and thereby strengthening their capacity to implement scientifically recommended primary processing methods for fennel (Bhardwaj et al., 2014). This positive shift highlights the crucial role of training and extension efforts in promoting the practical

TABLE 4 Effect of training on the gain in knowledge of the primary processing of fennel.

Various primary processing activities	Knowledge level (%)		
	Before intervention	After intervention	Gain in knowledge
Timely harvesting of fennel umbels	23	68	45
Construction of drying structure	47	82	35
Collection and transportation of umbel from the field to the drying structure	15	86	71
Grading of umbels before drying	10	70	60
Arrangement of the umbel in the drying structure	40	69	29
Collection of umbels after drying for threshing	16	66	50
Threshing of umbels	28	77	49
Removal of debris from fennel seeds	27	61	34
Winnowing of seeds	27	83	56
Cleaning of seeds	15	73	58
Grading of seeds	27	53	26
Packing of seeds	32	81	49
Total share in primary processing	26	72	47

TABLE 5 Change in knowledge level of farm women before and after training.

S.N.	Knowledge level	Pre-training (%)	Post training (%)	Increase per cent
1	Low	65	17	−73.84
2	Medium	20	52	160.0
3	High	15	31	106.0

TABLE 6 Change in the adoption level of farm women before and after training.

S.N.	Category	Before training (%)	After training (%)	Per cent increase
1	Low	73	40	−45.2
2	Medium	18	46	155.5
3	High	09	14	55.5

application of improved technologies among women farmers, ultimately leading to enhanced product quality, increased income potential, and greater participation in value-added agricultural activities.

Recommended technologies overview

The longitudinal assessment of the horizontal expansion of recommended technologies for the primary processing of fennel from 2008 to 2024 indicates a pronounced and progressive shift toward scientifically validated practices among farm women, reflecting enhanced technical capacity and sustained extension outreach (Table 7). Adoption of the recommended postmature umbel harvesting stage (31–40 DAFI) increased dramatically by 520%, rising from 10% in 2008 to 62% in 2024, while premature and over-mature harvesting declined by 54.55 and 57.69%, respectively, suggesting a growing understanding of harvest maturity as a determinant of seed quality and essential oil content.

Correspondingly, drying practices shifted from open drying and rudimentary shade structures to improved systems, with the modified locally made shade drying structure (integrating indigenous materials with a polyethylene sheet) increasing from 0 to 42%, and agro-shade net drying emerging at 13% adoption, indicating a clear preference for technologies that optimize drying efficiency while minimizing contamination. Similar trends were observed in threshing floors, where the decline in kaccha floors (−98.61%) and the 50% rise in plastic sheet (tripal) use demonstrate a rapid transition toward cleaner, more manageable surfaces; RCC pucca floors, though still low at 9%, reflect the early uptake of recommended durable infrastructure. Cleaning and grading technologies showed the strongest diffusion effect, with four-stage grading (the recommended standard) expanding from 0 to 45%, and three-stage grading rising to 30%, while ungraded produce declined sharply by 94.57%, underscoring the success of training in promoting value addition (Table 7). Packaging practices followed a similar modernization

TABLE 7 Horizontal expanse of recommended technologies for the primary processing of fennel.

Technologies of primary processing	2008	2012	2016	2020	2024	% Change
Umbel harvesting stages: recommended stage—post-mature stage (31–40 DAFI)						
Premature (20–30 DAFI)	11	9	8	7	5	–54.55
Post-mature (31–40 DAFI)	10	22	36	47	62	520.0
Over mature (41–45 DAFI)	52	51	41	34	22	–57.69
Drying (46–50 DAFI) stages	27	20	15	12	10	–62.96
Umbel drying structures: recommended structure—modified locally made shade drying structure						
Open drying	35	30	28	22	15	–57.14
Locally made shade drying structure	65	55	39	34	30	–53.85
Modified locally made shade drying structure (made up of local indigenous material + white polyethylene sheet on the roof)	0	15	28	35	42	42% (∞)
Agro-shade net house drying	0	0	5	9	13	13% (∞)
Types of threshing floors: recommended floor—RCC (Pucca floor) threshing floor						
Kaccha (Clay soil plastered)	72	55	23	8	1	–98.61
Cow dung plastered (Lipna)	20	28	39	32	20	0.00
Plastic sheet covered (Tripal)	8	17	38	46	76	850.0
RCC (Pucca floor) threshing floor	0	0	0	5	9	9% (∞)
Cleaning and grading of fennel seed: recommended stage—four-stage grading						
Without grading	92	70	45	20	5	–94.57
Two-stage grading (2 stage = pre and post drying of umbels)	8	20	28	25	20	150.0
Three-stage grading (3 stage = pre and post drying of umbel + 1 sieving)	0	4	9	23	30	30% (∞)
Four-stage grading (4 stage = Pre and post drying of umbel + 2 sieving + 1 mechanized)	0	6	18	32	45	45% (∞)
Packing and storage of fennel seeds: recommended material—gunny bag with polyethylene lining						
Plastic bag (empty fertilizer bag)	20	15	10	8	8	–60.00
Gunny bag (jute bag)	70	45	30	20	15	–78.57
Polyethylene bag	1	5	10	12	15	1,400.0
Gunny bag with polyethylene lining	0	20	50	60	62	62% (∞)

trajectory, as adoption of the recommended gunny bag with polyethylene lining increased from 0 to 62%, while traditional jute and fertilizer bags saw steep declines. Overall, the horizontal spread of technologies demonstrates a clear pattern of behavioral transformation driven by exposure to training, improved knowledge, and hands-on experience (Bhardwaj et al., 2014). These findings are consistent with global literature indicating that structured capacity-building significantly enhances farmers' adoption of post-harvest innovations, particularly among women, who are central to seed spice processing (Patel and Prajapati, 2018). The trends also corroborate evidence that adoption of improved post-harvest technologies reduces losses, improves product quality, and increases market competitiveness (Singh and Kaur, 2017; Acharya and Basu, 2020), while sustained technology diffusion at the community level strengthens local value chains and contributes to economic empowerment (World Bank, 2014). Collectively, the results confirm

that extension-led interventions have effectively catalyzed the diffusion of recommended technologies, positioning arm women as key agents in upgrading the fennel processing system in Sirohi district.

Conclusion

Tribal women's participation in the primary processing of fennel clearly shows they are the backbone of the post-harvest value chain, contributing over 88–89% of the labor across all major operations. Skill-oriented training interventions delivered through both on-campus and field-based programs proved crucial in strengthening technical skills among tribal women, leading to notable increases in income, employment, and socio-economic empowerment. Among tribal

women, who became the primary drivers of value addition within the fennel sector, this demonstrated that skill-oriented primary processing technologies, including scientifically timed harvesting, multi-stage grading, hygienic drying, efficient threshing, and improved packaging, significantly improve product quality, market value, and financial returns for fennel growers in Sirohi district. Training programs generated substantial increases in knowledge (up to 106% shift into the high category) and adoption levels (up to 55.5% rise in the medium category), clearly reflecting the transformative potential of structured capacity-building efforts for rural and tribal women. The long-term expansion of recommended technologies from 2008 to 2024 further confirms a sustained behavioral shift, with large increases in the adoption of scientifically validated practices such as post-mature harvesting (520% increase), multi-stage grading (up to 45% adoption), improved drying structures (42% increase), and safe packaging methods (62% adoption). Overall, the findings emphasize that empowering tribal women through scientifically designed primary processing interventions is essential not only for boosting production efficiency and profitability but also for fostering inclusive rural development in spice-growing ecosystems. Beyond socioeconomic benefits, these interventions enhanced asset ownership, saving behavior, technological access, engagement with extension services, and women's autonomy in household and community decision-making.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants or patients/participants legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

References

- Acharya, S. S., and Basu, S. (2020). Gender roles in post-harvest management in tribal agriculture. *J. Rural. Dev.* 39, 245–260.
- Ahmad, M., Nawab, K., Zaib, U., and Khan, I. A. (2007). Role of women in vegetable production: a case study of four selected villages of district Abbottabad. *Sarhad J. Agric.* 23, 1173–1179.
- Babbie, E. (2013). The practices of social research. 13th Edn. Belmont, CA: Wadsworth Cengage Learning.
- Bera, S., and Roy, S. (2020). Role of women in spice value chains in rural India. *J. Rural. Dev.* 39, 145–158.
- Bernard, H. R. (2017). Research methods in anthropology: qualitative and quantitative approaches. 5th Edn. Lanham, MD: Rowman and Littlefield Press.
- Bhardwaj, R. L., Nandal, U., Sarolia, D. K., and Vyas, L. (2013). Standardization of primary processing of fennel (*Foeniculum vulgare* mill.) in tribal area of Sirohi (Rajasthan). *J. Spices Aromat. Crops* 22, 11–19.
- Bhardwaj, R. L., Nandal, U., and Vyas, L. (2014). Impact of technology transfer for fennel primary processing on income and employment opportunities for tribal women in district Sirohi (Rajasthan). *J. Spices Aromat. Crops* 23, 205–210.
- Bojjagani, J., Babitha, B., and Suneetha, B. (2025). The role of farm women in post-harvest practices: an analytical review. *J. Sci. Res. Rep.* 31, 502–512.
- Choudhary, R., Meena, R. K., and Singh, P. (2022). Impact of post-harvest training on income enhancement among tribal women in Rajasthan. *Indian J. Ext. Educ.* 58, 102–108.
- Cochran, W. G., and Cox, G. M. (1950). Experimental design. New York: Pub. John Wiley Inc.
- Creswell, J. W. (2014). Research design: qualitative, quantitative, and mixed methods approaches. 4th Edn. Thousand Oaks, CA: Sage Publications.
- Department of Agriculture, Rajasthan (2022). Statistical abstract of Rajasthan agriculture. Jaipur: Government of Rajasthan.

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- FAO (2011). The role of women in agriculture. Rome: Food and Agriculture Organization of the United Nations.
- FAO (2013). Guidelines for data collection on agricultural technologies. Rome: Food and Agriculture Organization of the United Nations.
- FAO (2018). Guideline for the assessment of agricultural extension and advisory services. Rome: Food and Agriculture Organization of the United Nations.
- FAO (2023). Gender and agricultural value chains: empowering women for sustainable development. Rome: Food and Agriculture Organization of the United Nations.
- Farouque, M. G., and Anwar, A. B. M. N. (1998). Preference of female rural youth for selected activities in self-employment. *Bangladesh J. Train. Dev.* 11, 9–14.
- Gupta, R. P., Ghadei, K., and Panigrahi, S. P. (2024). Women's involvement pattern in grain management activities in Deoghar district of Jharkhand. *Indian J. Ext. Educ.* 60, 2–26.
- Jamali, K. (2009). The role of rural women in agriculture and its allied fields: a case study of Pakistan. *Eur. J. Soc. Sci.* 7, 71–77.
- Kabeer, N. (2005). Gender equality and women's empowerment: a critical analysis of the third millennium development goal. *Gend. Dev.* 13, 13–24.
- Kothari, C. R. (2004). Research methodology: methods and techniques. 2nd Edn. New Delhi: New Age International Publishers.
- Kumar, V., Sharma, A., and Devi, P. (2021). Crop diversification and spice production trends in India. *Agric. Rev.* 42, 212–220.
- Mehta, S., and Rathore, M. (2023). Economic benefits of improved post-harvest technologies in spice crops. *J. Post Harvest Technol.* 11, 55–63.
- Nandal, U., and Ojha, S. N. (2012). "Role of farm women in additional income generation through secondary agriculture" in Proceedings of global conference on women in agriculture at NASC complex, New Delhi, from 13–15 March, 2012, New Delhi: ICAR. 58–59.
- Naveen, S., Parida, J. K., and Panda, I. (2023). Tribal women empowerment through entrepreneurship: evidence from Mayurbhanj District, Odisha. *Front. Sociol.* 8:1158770.
- NITI Aayog (2021). Agriculture and rural development report. New Delhi: Government of India.
- Pandey, B., Yadav, D., Anand, N., and Suman, B. (2024). Tribal women in millet-based entrepreneurship: a glimpse of Odisha. *ShodhKosh J. Vis. Perform. Arts* 5, 640–668. doi: 10.29121/shodhkosh.v5.i2.2024.5479
- Patel, R., and Prajapati, H. (2018). Women's participation in post-harvest activities of seed spices in Gujarat. *Indian J. Ext. Educ.* 54, 120–124.
- Patel, D., Singh, R., and Jadeja, B. (2022). Farmer producer groups and market integration in India. *J. Agrar. Stud.* 14, 87–99.
- Rathod, U., and Patel, R. (2021). Women entrepreneurship in spice processing: opportunities and challenges. *Int. J. Rural Stud.* 28, 45–54.
- Rogers, E. M. (2003). Diffusion of innovations. 5th Edn. Mumbai: Free Press.
- Sagar, R. L., and Chandra, G. (2004). Evaluation of frontline demonstration on mustard in Sundarbans, West Bengal. *Indian J. Ext. Educ.* 3 & 4, 96–97.
- Samui, S. R., Maitra, S., Roy, D. K., Mandal, A. K., and Saha, D. (2000). Evaluation of frontline demonstration on groundnut (*Arachis hypogea* L.). *J. Indian Soc. Coastal Agric. Res.* 18, 180–183.
- Sanyang, S. E., Kao, T.-C., and Huang, W.-C. (2009). The impact of agricultural technology transfer to women vegetable production and marketing groups in the Gambia. *World J. Agric. Sci.* 5, 169–179.
- Sharma, H., Koli, M., and Dangi, L. (2020). Influence of primary processing on quality and price realization in fennel. *J. Spices Aromat. Crops* 29, 33–40.
- Singh, K., and Kaur, P. (2017). Labour division and women's contribution in seed spices processing. *Agric. Econ. Res. Rev.* 30, 89–98.
- Singh, A., and Meena, H. (2022). India's spice sector: growth, export performance, and future opportunities. *Spice India* 35, 12–18.
- Spices Board India (2023). Annual spice statistics report. New Delhi: Ministry of Commerce & Industry, Government of India.
- World Bank (2014). Gender in agriculture: closing the gap. Washington, DC: World Bank Group.