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Adaptation Strategies for Rainfed Millets (Ragi, Sorghum, and Samai) Against Climate Variability in the North Western Zone of Tamil Nadu: A Review with Reference to Dharmapuri District

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Abstract: The North Western Agro-Climatic Zone of Tamil Nadu, encompassing Dharmapuri district, faces significant challenges to rainfed millet cultivation due to accelerating climate variability. This review synthesizes current scientific evidence and on-the-ground experiences regarding adaptation strategies for finger millet (Eleusinecoracana), sorghum (Sorghum bicolor), and little millet (Panicumsumatrense) in this region. Dharmapuri district, characterized by red non-calcareous and red calcareous soils with low water holding capacity, receives an average annual rainfall of 942 mm, predominantly from the northeast monsoon, but recent years have witnessed alarming rainfall deficitsonly 690 mm recorded in 2025. Farmers in the region report declining millet yields due to erratic rainfall, prolonged dry spells, and increasing temperatures, with ragi yields declining from 10-20 sacks per acre historically to just 2-3 sacks in recent years.Adaptation strategies identified include: (1) adoption of drought-tolerant varieties suited to the zone, (2) intercropping systems with pulses (redgram, blackgram, horsegram) that improve system productivity and economic returns, (3) integrated nutrient management combining organic sources with inorganic fertilizers, (4) in-situ soil moisture conservation through mulching and farm pond construction, (5) contingency cropping planning based on rainfall patterns, and (6) integrated pest management using biological options. The benefit-cost ratios for millet-based intercropping systems in rainfed conditions reach up to 2.38, demonstrating economic viability. This review underscores that a holistic approach combining genetic, agronomic, and institutional adaptation strategies is essential for sustaining millet-based livelihoods in Dharmapuri district under increasing climate uncertainty.

Keywords: Rainfed millets, climate variability, Dharmapuri district, adaptation strategies, intercropping, drought-tolerant varieties.

1. Introduction

The North Western Agro-Climatic Zone of Tamil Nadu, comprising Dharmapuri, Salem, Namakkal, and Krishnagiri districts, represents a critically important region for rainfed agriculture in the state. This zone is characterized by an altitude ranging from 200 to 600 meters, receiving approximately 875 mm of annual rainfall, with the southwest monsoon contributing about 400 mm. The mean maximum temperature ranges from 30°C to 37°C, while the mean minimum temperature varies from 19°C to 25.5°C, and the length of the growing season is approximately 180 days. Crops such as finger millet (ragi), sorghum, groundnut, horse gram, sugarcane, cotton, and small millets are widely grown under rainfed conditions in this zone.

Dharmapuri district, which forms the northern part of this agro-climatic zone, presents a particularly challenging environment for rainfed agriculture. The district is severely affected by climate change, with poor precipitation characteristics observed over the last three decades. As per data from the disaster management team, Dharmapuri, which receives 942 mm of rainfall on average, only received 690 mm of rainfall in 2025. Farmers have attributed this low rainfall to the shortfalls of both the southwest and northeast monsoons, and over 30 of the 74 lakes spread over 100 acres have no water reserves. This water scarcity situation is compounded by the fact that over 80% of the area in Dharmapuri district is under dry land agriculture, with red sandy soils that are low in nitrogen and phosphate content.

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The challenges facing millet cultivation in this region are severe and multifaceted. Farmers from the Irula and SoligaAdivasi communities in the neighboringNilgiris region report that changing rainfall patterns make it increasingly difficult to farm millets like ragi, cholam, and samai. One farmer noted that his father used to get 10-20 sacks of ragi, but now he gets only 2-3 sacks from the same land. Another farmer lamented, "How will ragi grow in this heat?" reflecting the intense temperature stress affecting crop production. Changing eating habits have accompanied declining millet farming, with many communities replacing nutritious millet-based diets with rice from ration shops.

Despite these challenges, millets remain critical for food security, nutrition, and livelihood sustainability in this region. The cultivation of small millets such as samai (little millet) and ragulu (finger millet) provides farmers with climate-resilient crop options that are well-adapted to marginal environments. However, the sustainability of millet farming depends on the adoption of effective adaptation strategies that address the multiple stresses imposed by climate variability. This review synthesizes available evidence on adaptation strategies for rainfed millets in the North Western Agro-Climatic Zone, with a special focus on Dharmapuri district, to provide a comprehensive framework for enhancing resilience and productivity of millet-based farming systems.

2. Climate Context and Vulnerability of Millet Production in Dharmapuri District

2.1 Climate Characteristics and Recent Trends

The North Western Agro-Climatic Zone exhibits a semi-arid tropical climate with distinct wet and dry seasons. The normal rainfall pattern shows 47.6% (approximately 447 mm) received during the northeast monsoon, 33.7% (about 316 mm) during the southwest monsoon, 17.4% (164 mm) during summer, and only 1.3% (12 mm) during winter. This highly seasonal rainfall distribution, coupled with the region's red non-calcareous and red calcareous soils that have low water holding capacity (0-20% and 21-50%, respectively), creates significant moisture stress for rainfedcrops.

Recent climate trends in Dharmapuri district have been alarming. The district experienced a significant rainfall deficit in 2025, receiving only 690 mm against the normal 942 mm. This deficit has resulted in severe water scarcity, with over 90% of the 636 tanks (minor lakes and ponds) having no water reserves. Farmers have reported that over the past three years, summers have been extremely harsh, and crops have been damaged by intense heatwaves. The changing climatic conditions have also affected the Vanniyar basin in Dharmapuri district, where morphometric analysis has revealed that the basin is characterized by high susceptibility to erosion and sediment load, with a drainage density of 1.95 km/km² indicating very permeable soil.

2.2 Vulnerability of Millet Production Systems

The vulnerability of millet production in Dharmapuri district stems from the convergence of climatic, edaphic, and socioeconomic factors. The primary vulnerability factors include:

Rainfall variability and drought: Erratic rainfall patterns, including delayed onset of monsoon, prolonged dry spells during critical growth stages, and early cessation of rains, severely affect millet production. Farmers report that when it rained before sowing but not after, the seeds dried up and failed to germinate. This rainfall variability is compounded by the district's heavy reliance on groundwater, which is the primary source of irrigation but is increasingly depleted.

Soil degradation: The red non-calcareous soils of Dharmapuri district have low water holding capacity and are low in nitrogen and phosphate content. With declining organic matter content and increasing soil erosion due to high runoff, soil fertility has been deteriorating, further reducing crop productivity. The mean drainage density of 1.95 km/km² indicates permeable soil that drains rapidly, exacerbating moisture stress during dry spells.

Increasing temperatures: Rising temperatures during the growing season have been identified as a major constraint for millet production. High temperatures during flowering and grain-filling stages can cause flower shedding, reduce grain set, and lower yields. Farmers in the region report that the ragi plants grow more slowly now due to changing climatic conditions, with new varieties not performing as expected. However, the sustainability of millet farming depends on the adoption of effective adaptation strategies that

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address the multiple stresses imposed by climate variability. Human-elephant conflict: In areas adjacent to forest reserves, elephants have become a significant constraint to millet cultivation. Farmers joke that elephants seem to like ragi as much as they do, and many have stopped growing millets because of this threat. Solar fences provided by NGOs have helped some farmers resume millet cultivation, but the threat remains.

Socioeconomic vulnerabilities: The declining profitability of millet farming has forced many farmers to diversify into wage labor or migrate to urban areas. A report examining climate change and migration in Dharmapuri highlights how erratic climatic events act as primary "push" factors for cyclical migration. The loss of traditional knowledge about millet cultivation and consumption further compounds the vulnerability of these systems.

3. Varietal Adaptation Strategies for Rainfed Millets

Varietal adaptation is one of the most effective climate change adaptation strategies for sustaining rainfed millet production in drought-prone regions such as the North Western Zone of Tamil Nadu, particularly Dharmapuri district. Rainfall variability, prolonged dry spells, delayed monsoon onset, and increasing temperatures have significantly affected the productivity of traditional millet cultivation. The adoption of climate-resilient, high-yielding, and stress-tolerant varieties enables farmers to minimize yield losses while maintaining stable production under unpredictable weather conditions. Modern millet breeding programs have focused on developing varieties possessing drought tolerance, heat tolerance, early maturity, pest and disease resistance, and efficient nutrient and water use, making them suitable for rainfed ecosystems.

3.1 Early-Maturing Varieties

Early-maturing varieties complete their life cycle within a shorter duration, generally 90–110 days, allowing crops to escape terminal drought and high-temperature stress during the grain-filling stage. In Dharmapuri district, where the southwest monsoon is often erratic and rainfall distribution is uneven, early-duration cultivars provide greater yield stability than long-duration varieties. These cultivars also facilitate timely sowing of succeeding crops and reduce exposure to late-season moisture stress. The use of short-duration varieties has become increasingly important under changing climatic conditions because they require less cumulative rainfall while efficiently utilizing available soil moisture.

3.2 Drought-Tolerant Varieties

Drought tolerance is a critical trait for rainfed millet cultivation. Improved finger millet (ragi), sorghum, and little millet (samai) varieties possess physiological mechanisms such as deeper rooting systems, reduced transpiration rates, osmotic adjustment, improved water-use efficiency, and efficient stomatal regulation. These characteristics help plants withstand intermittent dry spells and recover rapidly after rainfall events. Compared with many cereal crops, millets naturally exhibit superior drought resilience, but varietal improvement further enhances productivity under water-limited environments. Adoption of drought-tolerant cultivars significantly reduces production risks for smallholder farmers dependent on rainfall.

3.3 Heat-Tolerant and Climate-Resilient Varieties

Increasing maximum temperatures during the reproductive phase adversely affect flowering, pollination, grain filling, and final yield. Climate-resilient millet varieties have been developed to tolerate elevated temperatures while maintaining normal physiological functions. Heat-tolerant cultivars exhibit improved pollen viability, better grain filling, and enhanced photosynthetic efficiency under high-temperature conditions. These varieties are particularly valuable in the semi-arid agro-climatic conditions of northwestern Tamil Nadu, where heat waves frequently coincide with moisture stress.

3.4 Disease- and Pest-Resistant Varieties

Climate variability often alters pest and disease dynamics, increasing the incidence of blast disease in finger millet, grain mold in sorghum, and various insect pests. Cultivating resistant varieties reduces dependence on chemical pesticides while ensuring stable

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yields under changing environmental conditions. Disease-resistant cultivars not only lower production costs but also contribute to environmentally sustainable agriculture by minimizing pesticide application. Integrating host plant resistance with other crop management practices strengthens the resilience of rainfed millet production systems.

3.5 Biofortified and High-Yielding Varieties

Recent breeding programs have emphasized the development of biofortified millet varieties possessing higher concentrations of calcium, iron, zinc, and dietary fiber while maintaining high grain yield under rainfed conditions. Such varieties simultaneously address nutritional security and climate resilience. High-yielding cultivars with stable performance across diverse environments enable farmers to obtain greater economic returns despite climatic uncertainty. The combination of superior nutritional quality and adaptability enhances the role of millets in sustainable food systems.

Table 1: Intercropping system performance

Intercropping System	Row Ratio	Equivalent Yield (kg/ha)	B:C Ratio
Little Millet + Redgram (T9)	8:2	985 (little millet), 362 (redgram)	2.38
Little Millet + Redgram (T7)	8:2	810	2.10
Foxtail Millet + Sesame	4:1	2,266	-
Finger Millet + Black Gram	4:1	2,895	2.84
Redgram + Greengram	-	1,207	2.29
Redgram + Soybean	-	-	2.29

3.6 Location-Specific Variety Selection

Selecting varieties according to local agro-climatic conditions is essential for maximizing productivity. In Dharmapuri district, where soils range from red loam to gravelly uplands with low moisture-holding capacity, varieties should possess drought tolerance, early maturity, and adaptability to low-input conditions. The selection of appropriate cultivars should also consider rainfall pattern, soil type, sowing season, and farmers' production objectives. Participatory varietal selection involving farmers and agricultural research institutions ensures that improved varieties meet local preferences and climatic challenges while encouraging wider adoption.

3.7 Recommended Climate-Resilient Varieties

Several improved varieties have shown good adaptation to rainfed environments in South India. For finger millet (ragi), varieties such as CO 15, GPU 28, GPU 67, and VL Mandua 352 are recognized for their drought tolerance, early maturity, and stable yields. For sorghum, K 12, CO 30, CSV 17, CSV 20, and CSV 27 exhibit good drought tolerance and grain productivity under rainfed conditions. For samai (little millet), CO (Samai) 4, Paiyur 2, and OLM 203 are suitable for marginal lands because of their early maturity, low moisture requirement, and adaptability to rainfed farming systems. Selection of these improved cultivars, together with appropriate agronomic management, can substantially improve climate resilience and livelihood security for millet growers in the North Western Zone of Tamil Nadu.

3.8 Development and Release of Drought-Tolerant Varieties

The identification and promotion of suitable varieties is a cornerstone of adaptation to climate variability in rainfed millet production. Research conducted at the Regional Research Station, Paiyur, from 2001 to 2006 led to the development of Paiyur 2, a long-duration high-yielding finger millet variety specifically suited to the rainfed conditions of the North Western Zone. This variety,

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a hybrid derivative of the cross VL145 x Selection 10, matures in 110-115 days and yields an average of 2,527 kg ha^{-1} of grain and 4,200 kg ha^{-1} of straw under rainfed conditions. It has compact incurved fingers, uniform maturity, non-lodging nature, and moderate protein content (7.2%). The 1,000-grain weight of this variety is 2.9 g, better than the 2.71 g of GPU 28.

For little millet (samai), three varieties are recommended for the North Western Zone: ATL 1, CO(Samai) 4, and Paiyur 2. Among these, ATL 1, released in 2019, is a drought-tolerant variety that produces 1,587 kg ha^{-1} with a duration of 85-90 days. It has a sturdy culm, non-lodging characteristics, and is suitable for mechanical harvesting. This variety is highly adapted to the Eastern Ghats districts, including Dharmapuri, Tiruvannamalai, Vellore, Salem, and Krishnagiri, and is also adaptable to plains under rainfedsystems.

CO(Samai) 4, released in 2006, yields 1,567 kg ha^{-1} with a duration of 75-80 days, making it suitable for the existing double-cropped rainfed situation in the zone. Paiyur 2 for little millet, released in 2000, is a short-duration variety (85 days) suitable for the little millet-horse gram cropping sequence, yielding 850 kg ha^{-1}. The adoption of appropriate varieties serves as a good coping mechanism to escape from moisture stress. For instance, farmers in Pennagaram block of Dharmapuri district took up cultivation of VRI2, a drought-resistant variety of groundnut that could cover the soil surface quickly by producing extra branches and leaves, which served as self-mulch, besides having good seed vigor and root penetration into the soil. Similar principles apply to millet varieties, where traits such as early maturity, drought tolerance, and synchronous flowering contribute to resilience.

3.9 Varietal Preferences and Local Adaptation

While released varieties provide a baseline for adaptation, local preferences and seed systems play a crucial role in ensuring the adoption of suitable varieties. Farmers in Dharmapuri district traditionally grew local varieties of ragi, cholam, and samai that were well-adapted to local conditions. However, with changing climate, many of these traditional varieties have become less productive, and farmers have had to switch to new varieties or abandon millet cultivation altogether.

The farmers from Irula and Soliga communities in the Nilgiris region reported that the ragi they get now doesn't smell or taste as good as it used to, suggesting that changes in varieties and growing conditions have affected grain quality. This observation highlights the need for breeding programs to consider not only yield and stress tolerance but also quality attributes that are important for local consumption and market acceptance. The development of variety-specific recommendations for different seasons and cropping systems is essential for optimizing adaptation. In the North Western Zone, millets are grown in three seasons: February-March (Masipattam), June-July (Adipattam), and September-October (Puratassipattam). Matching variety choice to the specific season and expected rainfall pattern can enhance the probability of successful production.

4. Agronomic Adaptation Strategies: Intercropping, Nutrient Management, and Soil Conservation

4.1 Intercropping Systems for Risk Diversification and Productivity Enhancement

Intercropping millets with pulses and other compatible crops is a proven strategy for enhancing system productivity, improving soil fertility, and diversifying income sources in rainfedenvironments. Research conducted at the Centre of Excellence in Millets, Tamil Nadu Agricultural University, on little millet-based cropping systems for rainfedagroecosystems demonstrated the effectiveness of intercropping with redgram.

The study evaluated nine treatments with different row ratios of little millet and redgram followed by pulses (moth bean, blackgram, or horsegram). The results showed that the 8:2 row ratio (little millet: redgram) followed by horsegram (T9) recorded the highest little millet equivalent yield (985 kg ha^{-1} and 362 kg ha^{-1} for redgram), with a gross return of ₹60,962 ha^{-1} and a benefit-cost ratio of 2.38. This treatment was followed by the 8:2 row ratio followed by moth bean (T7), which had gross returns of ₹51,314 ha^{-1} and a B:C ratio of 2.10. The study concluded that the 8:2 row ratio exhibited the highest little millet equivalent yield compared to 6:2 and 4:1 row ratios, and the highest economic return was observed in the little millet + redgram (8:2) followed by horsegram cropping system.

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Similarly, research on foxtail millet-based intercropping systems for rainfedagroecosystems in the north-eastern zone, which shares similar climatic conditions, demonstrated that the foxtail millet + sesame intercropping system in a 4:1 ratio exhibited the highest foxtail millet equivalent yield (2,266 kg ha^{-1}) along with notable relative production efficiency (10.5%) and relative economic efficiency (18.1%).

In Pennagaram block of Dharmapuri district, farmers have successfully implemented diverse intercropping systems through the Farmer Field School approach. In groundnut-based cropping systems, castor was used as a trap crop, sorghum as a border crop, redgram as a major intercrop, and cowpea as another intercrop. This diversified system, adopted by 280 farmers, provided multiple benefits: pest management through trap and border crops, enhanced soil fertility through legume intercropping, and diversified food and income sources. Sequential cropping was also promoted, with farmers cultivating blackgram or horsegram after harvesting the main crop, making use of residual moisture. Around 300 farmers cultivated horsegram as a sequential crop in 150 acres, which not only gave them extra income but also served as a source of fodder for animals.

Figure 2: Seasonal millet cultivation calendar for north western zone

Season	Tamil Name	Period	Crops
Early Season	Masipattam	February-March	Millets
Main Season	Adipattam	June-July	Millets
Late Season	Puratassipattam	September-October	Millets
Sequential	-	After main harvest	Blackgram, Horsegram

4.2 Integrated Nutrient Management and Soil Fertility Enhancement

Insufficient attention to soil nutrient management in dryland agriculture is common, and farmers in Dharmapuri district have identified reducing livestock populations as a reason for the non-availability and application of organic manure to soils. However, alternative options such as seed treatment, green manuring, enhancing biomass on farms, FYM enrichment, and use of biofertilizers and rock phosphate have provided new pathways for sustainable soil fertility management.

Seed treatment with biologicals: Seed treatment with biofertilizers like Azospirillum and Rhizobium, along with antifungal agents like Trichodermaviride, and soil application of Pseudomonas and Phosphobacteria along with FYM, strengthens plants from the start. This helps crops cope not only with pests and diseases but also with unfavorable environmental conditions such as moisture stress and nutrient-poor soils. Farmers observed that seed treatment with biologicals improved the rooting pattern, which further enhanced the crop's withstanding capacity during moisture stress.

Green manuring and biomass addition: Farmers in Pennagaram incorporated about 1-1.5 tons of sunhemp into their plots for the first time in 2012-13, enhancing soil organic matter content and nutrient availability. Measures such as higher biomass application through sunhemp, enriched FYM, and biofertilizers, coupled with effective in-situ soil moisture conservation, helped protect crops from severe moisture stress.

Organic manure application: The use of soil amendments like FYM and enriched FYM, along with biofertilizers and rock phosphate, helped keep soil profile and root zone temperatures lower during drought periods. Analysis of sample harvests showed significant differences between FFS plots (with organic amendments) and farmer plots in terms of pods per plant, plant population, branches, nodules, and overall biomass output. The application of higher quantities of FYM helped increase the moisture holding capacity of soils, providing resilience during dry spells. Contingency nutrient management: During moisture stress, farmers adopted contingency measures such as stubble mulching underneath redgram, which controlled further flower drops and resulted in mulched

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redgram plants yielding 0.5 to 1 kg higher than non-mulched plants. The use of rice gruel solution as a spray during active growth phases served as a drought management practice, with the gruel coating controlling the opening of leaf stomata and thereby reducing transpiration losses.

4.3 Soil Moisture Conservation and Water Management

In-situ soil moisture conservation is critical for rainfed millet production in the semi-arid environments of Dharmapuri district. The Government of Tamil Nadu has prioritized several strategies for enhancing climate resilience, including the construction of farm ponds, strengthening existing water harvesting structures, and repairing and replacing shutters in irrigation tanks and drainage channels.

Farm ponds and water harvesting: The government provides subsidies for the construction of farm ponds, and during monsoon failure or drought, farmers irrigate their fields with the help of water stored in these ponds. The Tamil Nadu Irrigated Agriculture Modernization Project (TNIAMP), a World Bank-funded project, includes components for rehabilitating and modernizing irrigation systems, including the construction of farm ponds. The Mission on Sustainable Dry Land Agriculture (MSDA) also includes the construction of farm ponds as a key component.

Check dams: Farmers in the North Eastern Zone have constructed a large number of check dams, and similar measures are being promoted in the North Western Zone. These structures help recharge groundwater and provide supplemental irrigation during dry spells.

Mulching: Mulching is essential across all agro-climatic zones, especially during drought and continuous dry spells. It creates an insulating layer, preventing rapid evaporation and maintaining moisture content in the soil. This practice enhances water-use efficiency, protects soil from erosion, and regulates temperature. Mulching is indispensable in drought-prone regions, contributing to soil moisture conservation and mitigating the impact of dry spells. In Pennagaram, farmers adopted stubble mulching as a contingency measure during moisture stress, which helped control flower drops and increase yields.

Land management techniques: Land management techniques like leveling, mulching, and minimal/zero tillage are recommended as part of good agricultural practices. These practices enhance soil moisture retention, reduce erosion, and improve the efficiency of rainwater use.

5. Institutional and Policy Support for Adaptation

5.1 Government Programs and Schemes

The Government of Tamil Nadu has implemented several programs to enhance the productivity and climate resilience of agriculture in the state. These programs provide institutional support for the adaptation strategies discussed in this review.

Tamil Nadu Irrigated Agriculture Modernization Project (TNIAMP): This World Bank-funded project focuses on improving irrigation systems and promoting climate-resilient practices. It includes components for rehabilitating and modernizing irrigation systems, promoting integrated farming systems, and supporting the construction of farm ponds.

National Agriculture Development Programme (NADP): This program provides support for various agricultural activities, including crop diversification and water management.

PradhanMantriKrishiSinchayeeYojana (PMKSY): This central government scheme focuses on improving water use efficiency through precision irrigation and other water-saving technologies.

National Food Security Mission (NFSM): This mission aims to increase the production of rice, pulses, and coarse cereals through area expansion and productivity enhancement. Millets, being coarse cereals, are covered under this mission.

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Rainfed Area Development (RAD): This program promotes integrated farming systems to protect from crop losses due to climate changes and make farming more productive and sustainable.

Mission on Sustainable Dry Land Agriculture (MSDA): This state initiative includes the construction of farm ponds as a key component and supports sustainable agriculture in rainfedareas.

Soil testing laboratories: Thirty-six soil testing labs and 16 mobile soil testing labs are functioning for analyzing soil and irrigation water, enabling farmers to make informed fertilizer decisions.

5.2 Farmer Field Schools and Knowledge Dissemination

The Farmer Field School (FFS) approach has been instrumental in promoting adaptation strategies in Dharmapuri district. Under this approach, farmers understand their crop ecosystems and learn to make crop decisions in groups. Local youth and women were trained as facilitators who conducted FFS sessions across villages, covering a wide range of topics: soil water conservation, soil fertility, crop biodiversity, integrated pest management (IPM), varietal choice, crop management, and harvesting.

The FFS approach enabled farmers to experiment and get convinced about biological and non-pesticidal management of crops. Farmers were encouraged to do biotic and abiotic assessments in farm ecosystems and decide pest management practices accordingly. For example, leaf-cutting experiments helped farmers avoid pesticide sprays. The importance of border crops and trap crops was demonstrated, and farmers tried out intercropping of groundnut with redgram and lablab, with sorghum as a border crop and castor and cowpea as trap crops for sucking pests.

In the case of samai, farmers tried sorghum as a border crop with redgram as an intercrop. Pheromone traps, yellow sticky traps, and light traps were installed in FFS plots. The yellow sticky traps, prepared using old mud pots, used water bottles, and plastic mugs, attracted thousands of sucking pests, convincing farmers of their effectiveness. Inspired by this, farmers in several villages prepared their own yellow sticky traps using locally available materials.

5.3 Crop Insurance and Financial Support

Crop insurance programs play a vital role in safeguarding farmers against climate-induced losses, providing financial security during periods of crop failure. However, the effectiveness of insurance in the context of rainfed millets depends on timely assessment of losses and prompt settlement of claims, which remains a challenge in many areas.

The government of Tamil Nadu has proposed developing and promoting flood and drought-resistant crop varieties to improve crop productivity across all agro-climatic zones. This initiative aims to enhance the overall productivity and stability of crop yields by introducing resilient crop varieties. Drought-resistant varieties are recommended to tolerate dry spells and moisture stress, ensuring better yields in case of deficient rainfall or drought.

The Uzhavan App, a mobile application providing farmers with information on government schemes, market prices, and agricultural advisories, represents an important digital tool for disseminating adaptation information.

6. Conclusion

This review examined adaptation strategies for rainfed millets (ragi, sorghum, and samai) against climate variability in Dharmapuri district, North Western Agro-Climatic Zone of Tamil Nadu. Key findings reveal that climate variability poses severe challenges, with rainfall deficits (690 mm in 2025 vs. 942 mm normal), rising temperatures, and prolonged dry spells causing drastic yield declines from 10-20 sacks to just 2-3 sacks per acre, exacerbated by soil degradation and human-elephant conflict. Varietal adaptation is critical, with drought-tolerant varieties like Paiyur 2 (2,527 kg ha^{-1}) for finger millet and ATL 1, CO(Samai) 4 for little millet providing resilience through early maturity and non-lodging traits. Intercropping (little millet + redgram in 8:2 ratio followed by horsegram) enhances productivity with a benefit-cost ratio of 2.38, while integrated nutrient management, seed treatment with

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biologicals, and organic manure application sustain soil health and reduce cultivation costs by up to 24%. In-situ moisture conservation through mulching, farm ponds, and check dams, supported by government programs like TNIAMP and MSDA, along with institutional support through Farmer Field Schools, are essential adaptation measures. Addressing socioeconomic challenges including labor migration requires strengthening market linkages, value addition, and awareness about millet nutrition. Integrating genetic, agronomic, and institutional strategies is crucial for sustaining millet-based livelihoods. Future research should refine adaptation packages for sub-zones, evaluate long-term sustainability, and develop decision-support tools, while policy must prioritize seed systems, credit access, insurance, and water harvesting infrastructure.

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