RICE MECHANIZATION IN ETHIOPIA: TRENDS, AND PROSPECTS
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ABSTRACT
The domestic rice industry of Ethiopia is constrained by low productivity, poor quality, and old processing machines. The rice production system is done by hand or with rudimentary tools, and only 2% of households have access to tractors. It takes 175 labor days to weed and 66% of the total farm operations. Rice harvesting and threshing are done manually using a serrated sickle and animal trembling respectively. Farmers are responsible for most of the pre-milling operations and store paddy for household consumption in local stores. Challenges include fragmented farm holdings, poor marketing channels, and a lack of awareness of post-harvest utilization. The prospects for rice mechanization development include improving the rice mechanization research system, training local entrepreneurs, providing repair and maintenance services, promoting custom hiring centers, local manufacturing of farm implements, organizing agricultural cooperatives, landholding, and land ownership structures, assessing foreign experience, linking importers and service providers, and encouraging investments in the rural infrastructure.

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INTRODUCTION
Rice *(Oryza sativa L.)* is an essential food crop for more than half of the population worldwide *(Ashtiani-Araghi H., et al., 2010).* It was introduced recently in Ethiopia and has been identified as "the new millennium crop of Ethiopia". It has been increasing at a rapid rate in both area coverage and farmers' involvement, reaching 121,000 tons in 2013 and 171,854 tons in 2019 *(Bekele, 2017; CSA, 2019; MoA, 2020)*. However, productivity is low compared to the potential of not suitable, marginally suitable, moderately suitable, and highly suitable areas with 39,931 ha, 312,135 ha, 629,320 ha, and 295,547 ha, respectively throughout the country or from rice hub areas *(Getachew et al., 2015).* There are seven major rice-producing areas, often named rice hubs, which are Fogera in Amhara, Pawi in Benishangul Gumuz, Abobo in Gambella, Chewaka in Oromia, GuraFerda in the Southern Nations, Nationalities, and Peoples' Region (SNNPR), May-Tsebri in Tigray, and Gode in Somali Regions *(Alemu and Assaye, 2021).* The current production is 81.2%, 18.6%, and 0.2% are rain-fed lowland, rain-fed upland, and irrigated accordingly *(Tefera, et al., 2011).*

Ethiopia's rice consumption is rapidly growing, mainly through imported rice *(Bekele, 2017).* This indicates that domestic supply is not satisfying consumer demand. Imports are increasing at an alarming rate, adding to the pressure on the country's inadequate foreign currency reserves *(Merkine, 2022).* Imports expanded from 22,500 t to 533,620 t with foreign currency payments of $12.07 million to $186.2 million between 2008 and 2019 *(Assaye and Alemu, 2020).*

The rice industry is an important source of revenue, and livelihood, which is utilized for both consumption and income to purchase household consumables. The crop has made its way into the local diet and is seen as compatible with traditional foods as well as drink-making. *Injera* (traditional flatbread) is now prepared by mixing a small amount of rice flour with Tef flour (a ratio of roughly one to five). This mixing is liked by customers because of their rising desire for the whiter-colored *Injera* that rice delivers*(Alemu, D., and Thompson, 2020).*

Rice production in Ethiopia is a labor-intensive crop, and all household members play important roles *(Kebede and Getnet, 2020).* Mechanization has the potential to save labor, increase productivity, reduce post-harvest loss, and raise the quality of rice processing. However, labor scarcity during the crop setup period prolongs the age of seedlings, and transplanting old seedlings affects rice yield *(Liu et al., 2017)*. Therefore, it is important to analyze the mechanization trends, challenges, opportunities, and prospects in rice production. This review is intended to provide a better knowledge of status and trends, as well as identify challenges and prospects. Hence, it examines the status, challenges, opportunities, and prospects of rice mechanization research and development in Ethiopia, using both academic and popular findings.

REVIEW METHODS

The review research method was divided into three phases: keyword searches were conducted using TEEAL, PubAG, JSTOR, AGRIS, local hard copies, and gray literature. Resources related to rice mechanization were also sorted sequentially in the Google and Google Scholar databases, chosen publications were evaluated and analyzed in greater depth, and research outputs from other countries were reviewed. The review is meant to be an updated version that can provide insight into research and development, as well as some early possibilities. This fast evidence evaluation was created by searching for relevant publications on the status, difficulties, possibilities, and prospects of rice mechanization both internationally and locally. It was arranged in portions step by step to provide an overview of rice cultivation and processing, including the current status, difficulties, possibilities, and threats.

RESULTS AND DISCUSSIONS

About 51 relevant documents were found in this review by assessing major databases and complementing them with gray literature. As a result, a good deal of pertinent research was discovered, such as peer-reviewed journal articles, literature reviews, forum proceedings, and conferences that give information concerning the trends and prospects of rice mechanization in Ethiopia. The methodological quality of the included studies was also examined through all sorts of investigations was included. Various trends and chances for rice mechanization in Ethiopia were discovered and thoroughly examined. As a result, the paper's conclusions are summarized into four categories: the status, obstacles, possibilities, and challenges of rice mechanization in an Ethiopian environment. The important findings on existing rice mechanization technologies in the country are discussed in detail in each chapter.

1. TRENDS OF RICE MECHANIZATION IN ETHIOPIAN

1.1. Status of Rice Mechanization

Ethiopia's rice farming practice is traditional, with small-scale producers with small farm sizes employed for land preparation, harvesting, threshing, storage, and processing *(MoA, 2020).* The status of agricultural mechanization in soil preparation, rice establishment, crop management, harvesting, cutting, collecting, threshing or winnowing, drying, and storage is backward. In the last two decades, different governmental and non-governmental organizations have tried to assess agricultural mechanized technologies in rice production, which will be discussed section by section.

1.1.1. Pre-Harvest Practices

Ethiopian agriculture is mainly smallholder farming, with 90% of farmers holding less than 2 ha per household. Oxen draft, besides human muscles, is the primary source of agricultural power for land preparation and planting *(FACASI, 2014).* The power provided by animals and people is utilized for all operations with conventional tools and implements, such as an animal-drawn "*ard-plough*" known as *"Maresha"(Kebede and Getnet, 2020).*In normal agricultural conditions, a pair of indigenous oxen is utilized to till with a draft force requirement of around 1.0 kN*(Gebreslasie et al., 2004).* The average working speed of oxen is 0.894 m/s, but the typical rate of utilizing horses is 0.75-1.07 m/s *(Geza, 1999; Gebreslasie et al., 2004).* Pre-harvest technology such as ploughs, harrows, planters, and weeders have been developed and imported from abroad, but effective implementation has been limited.

Some parts of Ethiopia, including Fogera, Gambella, and Pawe, have poorly drained Vertisol soil, making it difficult for farmers to prepare hard soil before the rainy season begins. This sticky quality of the moist soil following the onset of the rainy season creates difficulty in the timely seeding and maintenance of crops using draft animals *(Johansen et al., 2012).* All family members play a vital role in land preparation, including seed cleaning, seed drilling, and weeding *(Kebede and Getnet, 2020).* A precisely leveled field is a prerequisite for effective surface irrigation, sowing, transplanting, and harvesting operations. However, there is a challenge in developing and deploying land-leveling technology for rice production *(Getnet et al., 2019).* A household survey in the Gurafarda and Fogera plains reported that nearly insignificant farmers possess modern mechanized technology other than traditional farm tools as shown in Table 1*(Deribe et al., 2019).*

Table 1

Ownership of farm machinery and farm tools

Type of machine or tool	Ownership (%)			Maximum
	Fogera (N=278)	Gurafarda (N=65)	Total (N=343)	
Engine and manual or tool				
Two-wheel tractors	-	1.54	0.29	1
Harrow	-	1.54	0.29	1
Cultivator	-	1.54	0.29	2
Trailer	-	1.54	0.29	1
Water pump	19.06	7.69	16.91	5
Motorized water pump	14.39	1.54	11.95	2
Animal cart	3.24	-	2.62	2
Sprayer	66.55	50.77	63.56	3
Ordinary farm tools				
Plough (set) ("*Maresha*")	91.01	86.15	89.80	5
Saw	23.02	15.38	21.57	4
Sickle and forage cutting	95.32	86.15	93.59	13
Machete	1.80	61.54	13.70	6
Hand hoe	31.29	72.31	39.07	10
Spade	46.04	50.77	46.94	3
Mattock	12.95	18.46	13.99	5
Axe	85.25	86.15	85.42	6
Fork	9.71	7.69	9.33	7

Sources: A household survey (Deribe et al., 2019).

A household survey revealed that only 2% of rice farmers had access to tractors, with 1.8% in Fogera and 3.1% in Gurafarda. Tractors are used for initial ploughing before rain when soils are hard and animal traction for the second and third times *(Ayele, 2021).* Draft power users cultivate 0.81 hectares per household *(Deribe et al., 2019).*

Table 2

The use of mechanization by sample HH (%)

Type of operation	Fogera (N=278)	Gurafarda (N=65)	Total (N=343)
Tractor ploughing	1.80	3.07	2.04
Row planting	-	1.54	0.29
Chemical spray (manual)	5.03	6.15	6.48
Harvesting/threshing	0.72	-	0.58
Polishing	28.06	-	22.74
Grain grading	0.36	-	0.29
Improved storage	-	1.54	0.29

Sources: A household survey (Deribe et al., 2019).

Rice weeding requires 175 work days and 66% of all effort for various activities, making it a labor-intensive process. Moreover, weeding requires more work than harvesting and threshing. Women contribute to farm work in other ways as well; 75% of first-time weeding is done by women. The majority of the labor used on farms is hired labor, with male labor playing the dominant role and most farm households relying on family members*(Deribe et al., 2019).*

Table 3

Total labor used by the farm operation and locations (labor days)

Farm operation	Fogera (N = 278)	Gurafarda (N =65)	Total (N =345)
Primary tillage	7.79	8.08	7.36
Secondary tillage	7.57	7.67	6.83
Tertiary tillage	3.90	3.85	4.37
Row planting	14.34	15.97	8.08
1st weeding	76.08	79.91	68.08
2nd weeding	65.44	65.87	64.42
3rd weeding	33.29	27.20	55.79
Transport of harvest	11.88	9.29	15.96
Harvesting	27.34	30.60	20.08
Threshing	17.14	18.35	13.99

Source: A household survey (Deribe et al., 2019).

Research advances have been also made in manual 4-row rice transplanters, hand-pulled 8-row IRRI seeders, and animal-drawn four-row seeders *(Getnet et al., 2019).*In this regard, the rotary and push-pull type weeders were tested and demonstrated by NRRTC in collaboration with the Africa Rice project, with the rotary weeders alone increasing the grain yield of rice by 10.9%. Puddling after 10–15 days of flooding, combined with three times weeding with a small hand weeding supplement, plays a critical role in increasing yield *(Tadesse et al., 2019).* Farmers still use the *"Maresha"* plough for pre-harvest activities, requiring the introduction of mechanization technologies such as single axle and small horsepower tractors for land leveling, puddling, seeding, transplanting, water lifting, weeding, and chemical application *(Getnet et al., 2019).*

1.1.2. Harvesting Trends

In Ethiopia, rice harvesting is done manually using a serrated sickle at a rate of 200 to 240 man-hours/ha for cutting the standing crop and 20 man-hours per hectare for collection and piling *(Kebede et al., 2019).*

As shown in Table 3, the total labor and cost used by rice farmers during harvesting, primarily in the Gurafarda and Fogera plains, were 27.66 labor days per season, respectively, with 42% of households relying on shared labor to accomplish it *(Deribe et al., 2019).* Harvesting with a sickle has a working capacity of only 0.01 ha/h, which is why labor shortages during crop harvesting are a regular problem in Ethiopia *(Islam, 2009).* The lack of mechanized harvesters is the major cause of delays and significant losses due to it, with manual harvesting taking 3–5 days per hectare and incurring losses of 2-7% *(Toquero and Duff, 1974).*

Vertical conveying reapers (VCRs) have been introduced to address the challenge of shattering during the harvesting process. The Melkassa Agricultural Research Center acquired the technologies and evaluated them on the X-Jigna rice crop variety in the Fogera area, which had a 7.1% harvesting loss at 17% grain moisture content *(Kebede et al., 2019).* The Fogera National Rice Research and Training Center (FNRRTC) has introduced and promoted different-sized VCRs, which revealed that a VCR with 4.7 hp cannot perform well. 2WT attached reaper harvesters were harvesting efficiently, even though the adoption of those technologies was not adequately conducted. However, farmers, development agents, and government officials are challenged by the cost, supply, and access to maintenance and assembly services of the technology *(Kebede et al., 2019).*

1.1.3. Post-Harvest Operations

1.1.3.1. Rice Threshing Trends

Rice threshing is typically accomplished by oxen trampling on a layer of 15-20 cm thick harvested rice stalks spread on well-compacted and plastered hard surfaces, followed by manual sweeping and gathering of the grains. It takes two people with five oxen for 10 hours to produce one ton of fairly dried rice, but it is time-consuming, drudgery, and causes huge losses due to spreading fractures and a mix-up with soil impurities *(Amare et al., 2015).* Rural networks have an important contribution, in which 33% of households rely on shared labor for threshing operations. In some places, rice is threshed by beating bunches of panicles with sticks or on small straw-prepared fields without the use of tarpaulins, plastic, or canvasses *(Mutai et al., 2018).* The threshed paddy is then cleaned by tossing it into the air and blowing off most of the light chaff and other impurities that were removed during the field winnowing and de-stoning. Grains are then lost as spillage during this operation, and losses during winnowing can be as high as 4% of the total production. Currently, some communities utilize antiquated winnowing baskets, which depend heavily on natural wind for cleaning, but have limited efficiency in separating rice from debris *(Nath et al., 2017).*

Rice threshers have been developed and evaluated in Fogera. Bahir Dar Agricultural Mechanization and Food Science Research Center developed a hold-on pedal-operated rice thresher that consists of an open rotating drum with wire loops *(Amare et al., 2015).* The Fogera Rice Research and Training Center evaluated three types of engine-driven threshers using Edget and Nerica-4 rice varieties. The *"Selam"* thresher was manufactured by the *Selam*Technical and vocational training center, while the other two were imported from Indonesia and China as shown in Table 4 *(Kebede et al., 2019).*

Table 4

Main operating performances of the three rice threshers

Parameter	Ediget Variety			Nerica-4 Variety		
	Indonesian	China	*Selam*	Indonesian	China	*Selam*
The moisture content of the crop	9.5	9.5	9.5	13.87	13.87	13.87
Threshing capacity (kg/hr.)	606.06	500	416.67	632.9	606.06	588.23
Threshing efficiency (%)	98.2	99.5	97.3	98.5	99.75	96.5
Cleaning efficiency (%)	85.34	99.21	70	86.48	97.33	74.32
Total loss (%	1.05	0.71	3.15	0.845	0.465	3.985

Source: Field performance of rice threshers(Kebede et al., 2019)

FNRRTC introduced the PKG65 model, a rubber crawler-type axial feeding rice thresher machine used to harvest irrigated and muddy paddy fields. It can move throughout the field and thresh bundles, reducing extra time loss and drudgery for collection and pile-up. Farmers preferred it during a demonstration in Fogera Plain because it was easier to manage and less oppressive of the straw. It is recommended to be scaled up and further adopted for small-scale rice farmers.

1.1.3.2. Rice Processing Trends

Rice processing is a critical stage in the rice value chain, with farmers taking their paddy to urban commercial rice processors. Farmers are responsible for most of the pre-milling operations, but only a limited number of farmers are aware of the rice polishing practice *(Deribe et al., 2019).* Due to limited knowledge of the drying process, a significant amount of rice breakage occurs during the milling process *(Kebede et al., 2019).*

Rice processing in the Fogera plain has developed remarkably, with 123 registered and licensed rice processors, with an average annual growth estimated at 34%. Nationally, the number of registered rice processors has increased from 10 in 2009 to over 150 in 2018, and a modern large-scale rice-milling factory has also started *(MoA, 2020).*

The majority of milling machine types used in the Fogera and Gurafarda areas are single-pass Engelberg types with Nx-110, N-90, and N-70 models. However, limited numbers of double-pass SB milling machines with SB10, SB30, and SB50 models are also used, with milling recovery above 60% *(Kebed et al., 2019).* Recently, some processors have purchased new combined multi-level processing machines, but they are not functional due to limited access to infrastructure and working space. Multi-level machines are also common in Gambella areas, with good quality but higher prices in the market *(Assaye and Alemu, 2020).* Table 5, below shows various machine types with different processing capacities *(APRA, 2018).*

Table 5

Common rice processing machines models with their milling capacity in Fogera plain

Machine type in the model	Processing capacity (t/hr.)
N–90	0.8-1.3
N–70	0.9-1.5
Nx–110	1.0-1.2
SB–10	0.05-0.075
SB–30	1.0-1.5
SB–50	1.8-2.3
Multi-level processing	2.5

Source: Milling machine assessment report in the Fogera Plain (APRA, 2018)

Processors are buyers and sellers of rice in Ethiopia, and have incentives to process poorly to increase the volume of by-products and sell them for livestock feed for 1 Birr to 3.5 Birr (US$0.03 to US$0.10) per kg. As grazing lands were reduced in the Fogera Plain due to the expansion of rice, stall feeding became more common *(MEDA, 2019).* Locally milled rice is poor in quality, usually consumed locally, and cannot compete with imported ones in both price and quality. Improvement of the quality of locally produced rice in terms of the physical and cooking attributes of the grain is necessary to make it competitive *(Halos-Kim, 2014).* Business relations between farmers and processors or millers and other supporting agencies are fragile, with farmers claiming that the processors and millers do not reward them for their production investments and rice buyers regretting that the farmers fail to supply quality products in sufficient quantities. Rice processors continued using older processing machines with limited ownership of other required facilities for producing quality rice *(Assaye and Alemu, 2020).*

Parboiling is the other rice processing procedure in which the paddy is soaked in warm or cold water followed by steaming and drying before milling *(Kebede et al., 2019).* It is new and domestic marketing is underdeveloped in Ethiopia, but some processors access electric rice parboiling machines through matching grants with MEDA. The FNRRTC has introduced GEM (Grain Quality Enhancer, Energy-efficient, and Durable Material) parboiling technology, and some youth groups have started to make money through parboiling and byproduct processing. Continuous training and capacity building of processors and farmers are essential for the sustainable quality improvement of the rice processing industry *(Assaye and Alemu, 2020).*

1.1.3.3. Rice Grain Storage and Packaging

Rice post-harvest losses in Ethiopia are estimated to be 10-22%, with qualitative losses as high as 50%. Sun drying is the common drying method in the value chain before storage and processing *(Kebede et al., 2019).* Most Ethiopian farmers store paddy for household consumption in local stores, with Gotera, gotta, keffo, golota, meaqen, walla, jute or Hessian sacks, skin bags (aqomada/loqota, aybet), clay jars, gourds, wooden boxes, metal drums or barrels, and underground pits *(Tadesse et al., 2008).*

On the other hand, processors, and assemblers in small towns store their goods in 50-100 kg plastic or polythene bags that are sewed with a nylon string using a hand sewing tool *(Kebede et al., 2019).* Domestic rice packaging at the retailer's level is also at 0.25, 0.5, and 1 kg using plastic bags. These packaging methods expose the stored grains to different deterioration agents, while the appropriate management and monitoring of the entire set of influencing factors haven't been considered.

Pest infestation due to insects and rodents causes huge losses and is incapable of protecting long-term storage; the grain is periodically fumigated to control insect infestation but may cause long-term health cases.

The FNRRTC has demonstrated rice-sealed storage units of metal silos and PICS bags in the Fogera plain *(Kebede et al., 2019).* These technologies are used on sorghum, maize, and soybean crops in Ethiopia's four major regions to reduce stored grain losses for at least six months *(Obeng-Ofori, 2011).* A metal silo storage facility is a cylindrical structure with a capacity of 300-1000 kg made of 0.5 mm thick galvanized iron sheet. PICS bags are made up of three nested plastic bags and are suitable for the hermetic storage of dry grains. Metal silo and PICS bag storage methods offer economic impact by facilitating storage and sale later in the season when grain prices are higher *(Kebede et al., 2019).*

The collaboration of the Melkassa agricultural research center around grain storage technologies, specifically metal silos, was distributed and adopted in 2017, depending on the interest of rice farmers. About 150 silos were produced and distributed to farmers through a cost-sharing approach by the MEDA project. Six local manufacturers from Fogera, Dera, and Libokemkim were selected, trained, and certified.

1.2. Challenges in the rice mechanization

Despite increased rice production and area coverage in several sub-districts, rice mechanization remains limited and falls short of potential due to a lack of skilled manpower, credit, policy support, land fragmentation, lack of customized tools, farm machinery access, legislation, and other related issues *(Bekele, 2017).* Land size, cropping pattern, and market price are the major factors determining agricultural mechanization, and the average farm size per household in the main rice production plains of Gurafarda and Fogera is 2.40 ha and 0.89 ha, respectively *(Deribe et al., 2019).* Mechanizing small and non-contiguous groups of small farms is against economies of scale because the continued shrinkage in average farm size will make it difficult for individual ownership of agricultural machinery and progressively more uneconomical *(Sims and Kienzle, 2017; Mehta et al., 2014).* Small and fragmented land holdings or subsistence agriculture are the main impediments to the promotion of agricultural mechanization in the country, with similar conditions in other countries like Nepal *(Shrestha, 2011).*

The most important details in this document are that the country's mechanization development is hindered by a poor marketing channel and a lack of knowledge about mechanization management and utilization. Despite the existing demand for tractors, harvesters, and rice processing machines, farmers had poor access to services, such as a lack of credit to pay for hiring services and limited access to credit for the purchase and ownership of machines. Additionally, the country was importing tractors and other farm implements mainly from China, which was not up to the desired standard, resulting in poor quality of work, longer downtime, low output, and high operational costs. Besides, due to the country's lack of foreign currency, the prices of imported machinery are very high and out of reach for poor farmers. As a result, some farmers and processors have lost faith in mechanization technologies *(Derbe et al., 2019).*

The existing imported agricultural machinery, spare parts, and workshops in Ethiopia do not have standardized quality control facilities to ensure their quality. There should be a common facility center for agricultural machinery and spare parts production, and agricultural machinery testing and certification. Implementation of appropriate-scale agricultural mechanization would be a solution for sustaining the development and growth of the sector. Advisory, training, and technical services should work in collaboration with the BoA, suppliers, and dealers, and an adequate skilled workforce in the agricultural engineering field of study is critical. Private and governmental training centers are not efficiently available in rice-based farming, and the sub-sector is lacking at almost all levels of repair, maintenance, and management of farm machinery.

The other essential concepts in this text are the low access to research facilities on rice-based mechanization technology in Ethiopia. National rice research and development is mandated under the FNRRTC, but the agricultural mechanization workshop and laboratory facilities are not sufficiently organized.

Day-to-day research is conducted through the introduction of technologies from abroad, followed by validation and participatory evaluation for further adoption. External support and cooperation are inadequate, and the annual budget allocation for research is limited. Domestic capital expenditure on agriculture has shown a sharp decline recently, and neither loan-based nor assistance-based financing of the sector seems to be sustainable. The government allocated more than 10% of its budget to agricultural development, but agricultural mechanization and its development plans should have received more attention *(Alemayehu, 2002).*

In Ethiopia, there is no comprehensive policy or actionable plan for agricultural mechanization *(Tamrat, 2016).* In recent years, the Ministry of Agriculture and the Ethiopian Agricultural Transformation Agency (ATA) initiated the "Ethiopian National Agricultural Mechanization Strategy" in 2014, but it has not made any deals about the rice mechanization sector. This gap could be a sign of the slow expansion and development of agricultural mechanization in the country. Farmers in rural areas are characterized by poor road infrastructure and quality, isolation from markets, a lack of vehicles, and inefficient truck logistics, further increasing transport costs and discouraging them from commercializing their production. Mechanized farming needs access from farm machinery to the crop field, but most rural areas do not have adequate farm roads *(Alam and Khan, 2017; Islam, 2018).*

The public sector should have the role of putting in place policies to enable farmers to supply, assemble, maintain, and service farm machinery *(FAO, 2014).* Private repair and maintenance workshops are mostly equipped with repairing parts, but operators are not readily available at the district level. After-sales service of farm machinery is also a concern, as the majority of farmers are cost-conscious. Ethiopia's government offers free credit to farmers and local service providers, but it is not well organized and utilized in the Fogera and GuraFarada areas of the Amhara and SNNP regions respectively.

1.3. Opportunities for Rice Mechanization Development

Ethiopia has the potential to develop rice mechanization due to its 30 million ha of rain-fed rice production and ten river basins with the potential for irrigated rice *(MoA, 2010).* The vast potential area suitable for rice farm topography, especially in Fogera and Gurafarda, is the flat to moderate slope, making it less likely to affect the use of agricultural machinery. Demand factors have driven Ethiopian smallholder farmers to start rice production, and market-related opportunities include higher price value of rice grains and increased rice consumption habits *(Alemu, 2015).*

The MoA with ATA initiated the establishment of the Agricultural Mechanization Strategy, which aims to increase national productivity through enhanced and sustainable use of agricultural mechanization technologies to support Ethiopia's middle-income country by 2025. It aims to raise all levels of Ethiopian agricultural mechanization from 0.1 kW/ha to 1 kW/ha, reduce the use of animal power by 50%, promote the usage of agricultural mechanization technologies that can be used by female farmers, mitigate environmental degradation, and address at least 50% of the needs of pastoralists and agro-pastoralists through mechanization inputs *(MoA, and ATA, 2014).* The National Rice Research and Development Strategy has been developed by MoA with the close collaboration of the different organizations that compile overall rice research and development direction in the country. The research side of the strategy is intended to be implemented by FNRRTC and other research centers, but they need to build capacities such as agricultural machinery workshops and laboratories.

The increase in production, import, and consumption of rice has received attention from the government and development partners *(Alemu and Assaye, 2021).* Relevant stakeholders have shown their interest in playing their roles to realize the introduction and utilization of farm mechanization technologies through on-farm demos and partnerships with all national and international stakeholders *(Belete, 2019).* Free taxes and duties on imported agricultural machinery have made the import of agricultural machinery cheaper, motivating local importers to supply at cheap prices. Both governmental and private financial institutions and credit centers are available in the Ethiopian economy, but special attention should be given to collateral *(Kamruzzaman et al., 2009).* Banks now offer hire-purchase loans for agricultural machinery but are dominated by government banks. The motivations of farmers for agricultural mechanization technology will also be an opportunity to motivate the speed of technology adoption.

1.4. PROSPECTS OF RICE MECHANIZATION IN ETHIOPIA

Ethiopian smallholder farms need to shift to labor-saving devices and products to increase agricultural productivity, and appropriate mechanization technologies should be available to reduce drudgery and increase productivity *(Ayele, 2021; Diao et al., 2016).* Based on a review of various studies, recommendations are drawn for the development of rice mechanization in Ethiopia.

1.4.1. Institutional Strengthening

The Rice Mechanization Research System should focus on the physical capacity building of workshop machines, laboratory instruments, and on-farm test sites to promote farm mechanization. Establishing maintenance and assembly centers with adequately trained agro-mechanics and workshop technicians is needed for the promotion of mechanization extension programs. Capacity building of indigenous entrepreneurs is essential for the production of farm machinery prototypes that are adapted to fragmented lands and small holdings. Large-scale demonstrations are required to conduct research and development institutions, and feedback collection on the technologies' usage by end-users is essential. Farmers cannot learn overnight, and they need regularly updated processes of lifelong learning.

1.4.2. Facilitate Corporate Farms

Organizing agricultural cooperatives would be better because they could buy their inputs and sell their total produce together. Various joint farming ventures are profitable experiences in New Zealand, Canada, Portugal, Denmark, Norway, the Netherlands, France, and the UK *(Macken-Walsh and Roche, 2012).* The average farm landholding in Ethiopia is less than 2 ha and is decreasing due to the increasing population. Land holdings need to be consolidated to give their owners access to the benefits of agricultural mechanization. Ethiopia's mountainous terrain and fragmented land holdings mean that promoting small-scale machinery can be suited to Ethiopian conditions. Small-scale mechanization can be suitably used for highly fragmented land with a vibrant private sector, academic engagement in policy processes, and localized technology interventions.

1.4.3. Integrating Public-Private Partnership

Ethiopian researchers and higher learning institutions have a critical role to play in investigating mechanization options. There is a need for a clear division of roles between the public and private sectors. The public sector is best suited to providing subsidies, reducing transaction costs, and promoting the use of new technology *(Atilaw et al., 2017).* Experiences from African and Asian countries suggest that public-sector-supported private-sector mechanization is the best model *(Agricultural Mechanization Forum of Ethiopia, 2018).* Sales outlets that are within easy reach of farmers are essential to the development of a successful and sustainable private farming system *(Clarke, 2000).* Special attention is needed to create conditions so that importers, distributors, and small retail outlets can develop. These commercial units may range from a small, one-family shop in a village to a large national distributor for domestically produced and imported machinery.

1.4.4. Improve the Rice Value Chain

The supply chain approach to analyzing mechanization is a useful framework to describe the extent and typology of mechanization processes taking place in Ethiopia. The supply chains for mechanization cover the manufacturing and importation of machines, mechanized service provision, and spare parts and repair services for machinery maintenance *(Diao et al., 2016).* Ethiopia's Ministry of Agriculture needs to promote an improved paddy and milled rice marketing system, with the possibility of incorporating rice into the Ethiopian commodity exchange trading platform *(Assaye and Alemu, 2020).* The government of Ethiopia must prioritize mechanization throughout the entire rice value chain, not just at the production level. More focus should be placed on post-harvest and processing technologies that assist in boosting the commercialization of farmers' production *(A Malabo Montpellier Panel, 2018).*

Local manufacturers should be supported wherever possible to create implements and equipment adapted to local circumstances. Lessons to be adopted from the Chinese experience in making mechanization accessible to smallholder farmers are subsidies, strong extension services, and infrastructure development *(Sims and Kienzle, 2016).*

1.4.5. Strengthening the Local Manufacturers

Training of local manufacturers and maintenance personals on small-scale mechanization technologies should be conducted on the operation, maintenance, assembly, and management of agricultural machinery. Experiences from emerging countries like India, China, Brazil, Thailand, Bangladesh, Nepal, the Philippines, Myanmar, etc. showed that the rapid expansion in farm machinery demand has stimulated the growth of local machinery manufacturing. Local manufacturing of farm tools and implements is another crucial factor for the sustainable development of agricultural mechanization in Ethiopia *(FAO and UNIDO, 2008).* The fabrication of metal silos is a good example of what can be done to increase their market locally and is an opportunity for the local manufacturing industry *(Singh, 2015).* Private sector-led mechanization has been growing, with improvements in two-wheel tractors. The Nazareth Tractor Assembly Plant in Ethiopia assembles roughly 300 tractors per year, which accounted for 46% of tractors entering the Ethiopian market between 2005 and 2010 *(World Bank, 2012).*

1.4.6. Infrastructure Investments

Promoting rural infrastructure investment attracts investment in agricultural infrastructure, particularly irrigation, and roads, and adds value to farm outputs through agro-processing at the community level *(FAO and UNIDO, 2008).* Roads should be constructed in rural areas for the movement of tractors, bulldozers, combines, and other heavy farm implements and machinery. Farmers must have local access to the inputs they need, including seeds and fertilizers, electricity, and water, as well as machinery and the supporting infrastructure that mechanization requires. Despite local government pledges to guarantee the availability of electricity and access to reliable power for industrial purposes, rice processing is still challenged by it and needs to be overcome before processing expansion can be realized. Proposals to professionalize rice processing in Ethiopia include providing formal training for the operation and maintenance of rice processing facilities and increasing the availability of agricultural machinery and equipment *(Assaye and Alemu, 2020).*

1.4.7. Finance and Credit Facility

Increased capitalization of agriculture needs sources of finance on favorable terms, whether from the private sector alone or a blend of private and public capital. The financial sector should work with commercially oriented farmers and entrepreneurs to strike the necessary financial deals that are required for increasingly commercialized farming *(FAO and UNIDO, 2008).* Enabling smallholder farmers' access to credit is part of the policies and strategies to improve the productivity of farmers. Commercial banks should be available to farmers at lower interest rates, and co-operatives and microcredit institutions should serve as intermediaries between formal banks and smallholder farmers *(Clarke, 2000).* Microfinance institutions should offer a basic credit facility for both low-cost and motorized equipment including crop protection and irrigation tools.

1.4.8. Safe and Friendly Mechanization Technology

Ethiopia could continue to use animal traction in a combination with engine power by making significant innovations in the implements and by improving the oxen's body condition. The progressive farmers in the hills are in search of appropriate agricultural tools and machinery, but they fail to get into the local markets. Experience shows that for small farmers, the pathways for mechanization technology, especially tractor adoption, are between two-wheel tractors (2WTs) and four-wheel tractors (4WTs). Ethiopia's government has a lot to learn from Asian and African experiences, as well as from its own experience. In Ghana, promoting affordable, smaller tractors suitable for local soil and farming conditions is a key part of the agricultural development strategy. In Thailand, 2WTs have been increasingly adopted, substituting for the use of draft animals, while 4WTs are dominant in India and Nepal *(Agricultural Mechanization Forum of Ethiopia, 2018).* Strategically selecting appropriate technologies and practices from other rice-producing countries in Africa and Asia and adapting them to Ethiopian conditions is also a critical recommendation. Policymakers need clear options backed by evidence. Research reports recommended that strategizing the training and outreach activities of NRRTC is essential to strengthening the capacity for research-based selection of safe and friendly mechanization technologies in all value chain actors and stakeholders of the national rice mechanization system *(Alemu and Thompson, 2020).*

1.4.9. Policy Recommendations

The most important concepts in this section are the structures of landholding, incentives and support measures for mechanization, preferential treatment on capital machinery importation, and multiple value-added taxes on imported raw materials.

Land consolidation is the most important policy instrument, and legislation on land leasing, contract farming, and land banking are suggested options for promoting the mechanization and commercialization of agriculture *(Clarke, 2000).* Tax and subsidy rationalization is needed to promote the use of farm machinery without distorting the market. An immediate work plan is needed for the development of strategies and action plans for the implementation of the new Agriculture Mechanization Promotion Policy. Other critical issues to be considered are custom hiring support of a mechanization service provision through private and cooperative agents, improving smallholder access to mechanization, and unleashing human energy. Mechanization should be part of the government's long-term economic development strategy. This review was developed to help entrepreneurs and advocacy groups involved not only in rice but also in agricultural mechanization in the general start or continue a dialogue with policymakers and major donors to develop policies and programs that will allow the nexus to grow and provide transformative services to communities.

CONCLUSIONS AND RECOMMENDATIONS

Ethiopia is importing rice at more than three times the amount it is producing domestically. Rice mechanization has the potential to increase productivity by saving labor, minimizing drudgery, reducing post-harvest loss, and increasing rice quality. In the last two decades, different governmental and non-governmental organizations and the private sector have been involved in accessing rice mechanization technologies. However, the status of agricultural mechanization indicated that each rice production system was done by hand or with rudimentary tools or types of equipment, as well as traditional animal-drawn implements. Draft power is so important for primary tillage that 93% of households rely on livestock, primarily oxen.

Rice harvesting is done manually using a serrated sickle for cutting the standing crop and a further 20 man-hours/ha for collection and piling. Farmers are responsible for most of the pre-milling operations, with 78.8% of the farmers selling unprocessed rice. Processors and assemblers are also in small towns and are stored in their homes, mill houses, or small storage rooms using 50 to 100 kg plastic bags. The major challenges and constraints to this low level of rice mechanization are fragmented farm holdings, poor marketing channels, a lack of awareness of pre-harvest management and utilization, a scarcity of pre-and post-harvesting technologies, lack of finance and a lack of hiring service providers, an intensive cropping pattern, a supply of poor quality machines, an inadequately skilled workforce, and limited research facilities.

However, Ethiopia has some opportunities for rice mechanization research and development, such as the development of a mechanization strategy, free taxes and duties on imported agricultural machinery, suitable rice farm topography, farmer motivation and awareness of agricultural mechanization technology, and the establishment of a national rice research and training center (NRRTC). Hence, the way forward for this low level of rice mechanization is improving the research system, training local entrepreneurs, repair and maintenance services, promoting custom hiring centers, local manufacturing of farm tools and implements, organizing agricultural cooperatives, improving landholding and landownership structures, assessing foreign experiences, linking machine importers and service providers, and encouraging investments in the rural infrastructure.

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