Review Paper

Coffee Production Challenges and Opportunities in Tanzania: The Case study of Coffee Farmers in Iwindi, Msia and Lwati villages in Mbeya Region

Abstract

Coffee is one of the most popular and grown cash crops in Tanzania. However, its productivity has remained low due to various biotic, abiotic and socio-economic factors prevailing in Mbeya Region. These production challenges have never been properly and intensively documented for better research and management decision making by the government and other research institutions. Therefore, this study was set to assess and provide a better understanding of the current production situation and link the identified challenges to potential management strategies for better coffee production in Mbeya Region.

The research was carried out in Iwindi, Msia and Lwati wards located in Mbeya Region. Two sources of data were used; a) primary data collected through focus group discussion and b) secondary data collected through a systematic and intensive process that involved searching and collecting relevant publications.

From the research, farmers were found to grow old trees averaging 22 years. Soils have low levels of macronutrients, micronutrients and organic matter. The soils are acidic with pH below 5.5. High prevalence of pests (e.g. berry and stem borers) and diseases (e.g. coffee leaf rust, *Fusarium* spp., bacterial blight of coffee and red blister). Poor agronomic practices involving intensive intercropping of coffee with other food crops and using generally low tree densities per hectare was also observed. Poor extension services (extension agent to farmer ratio is about 1:1800) was found to be one of the causes for poor adoption of best coffee agronomy. Lack of market information and constantly low prices have been found to demoralize farmers as it leads to a low return on investment. When asked for their 'priority training and input support requirements', all farmers mentioned training on best coffee agronomy and fertilizer use; fertilizers inputs (especially Urea, Calcium of ammonia nitrate or Yara Mila Java blend products), pesticide for berry and stem borer pests and fungicide inputs as their key requests. All these inputs and training require money and service provider. Bundling of training and inputs together could make it easier for any service provider to help farmers increase their yields.

Keywords: Coffee, production challenges, Mbeya Region, soil fertility management, pest, and disease management

1. **Background Information**

Coffee is one of the most popular and grown cash crops in Tanzania. Nationally, the crop accounts for about 5% of total exports (generating export earnings averaging US$ 100 million per annum) and provide employment to over 400,000 farmers[1, 2]. Mbeya region, located in the southern highlands, is among the leading producers in terms of area and yields. Other coffee producing regions are as shown in **Figure 1**. Despite the importance of the crop to the economy, its productivity is still low at 200-750 kg/ha compared to the potential of over 3 t/ha of most of the varieties under best management[3]. **Figure 2** shows the current coffee production figures in Tanzania. Such low yields coupled with highly regulated low prices leave farmers running at losses. Low coffee yields and poor return on crop investment could be attributed to climatic, edaphic, biotic and socio-economic constrains[4]. Despite many available technologies existing in the coffee world that can be adapted for Mbeya Region for better production, farmers have poor access to such information and hence continuing to produce using local technologies that reduce yields. This could be because of poor agricultural extension service not capable of disseminating information. It is reported that extensional service only reaches 10% of Tanzanian farmers[5]. The level of illiteracy is also high among farmers making it difficult to synthesize, adapt and adopt available information and technologies. Base on this background, there is a compelling need to have an in-depth assessment into what the current coffee farming conditions look like, how much yield gap exists and what are the management bets with low complexities for dissemination and adoption.

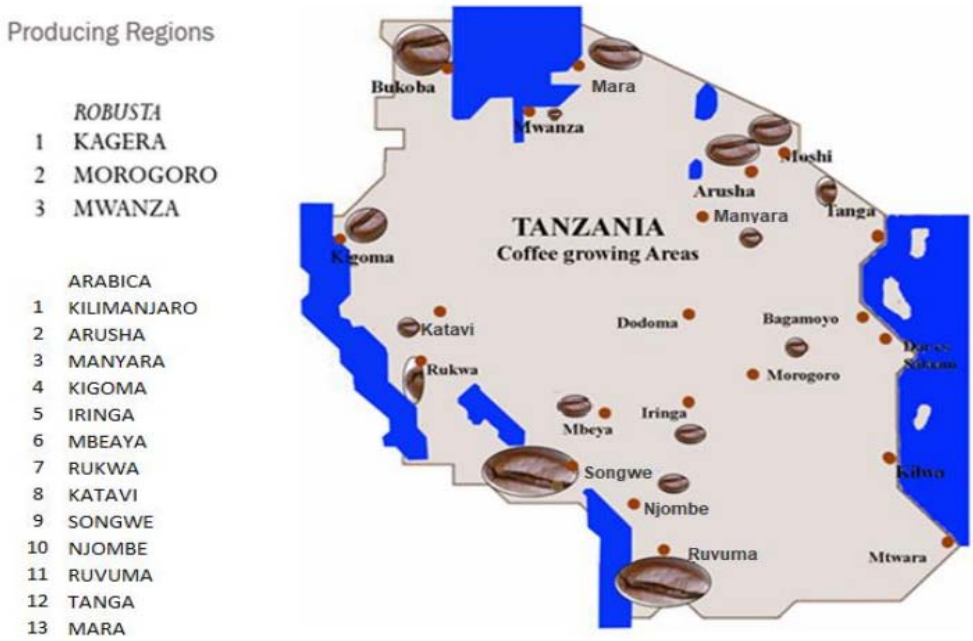

Figure 1: Coffee producing areas in Tanzania. Source: Tanzania Coffee Business Directory.

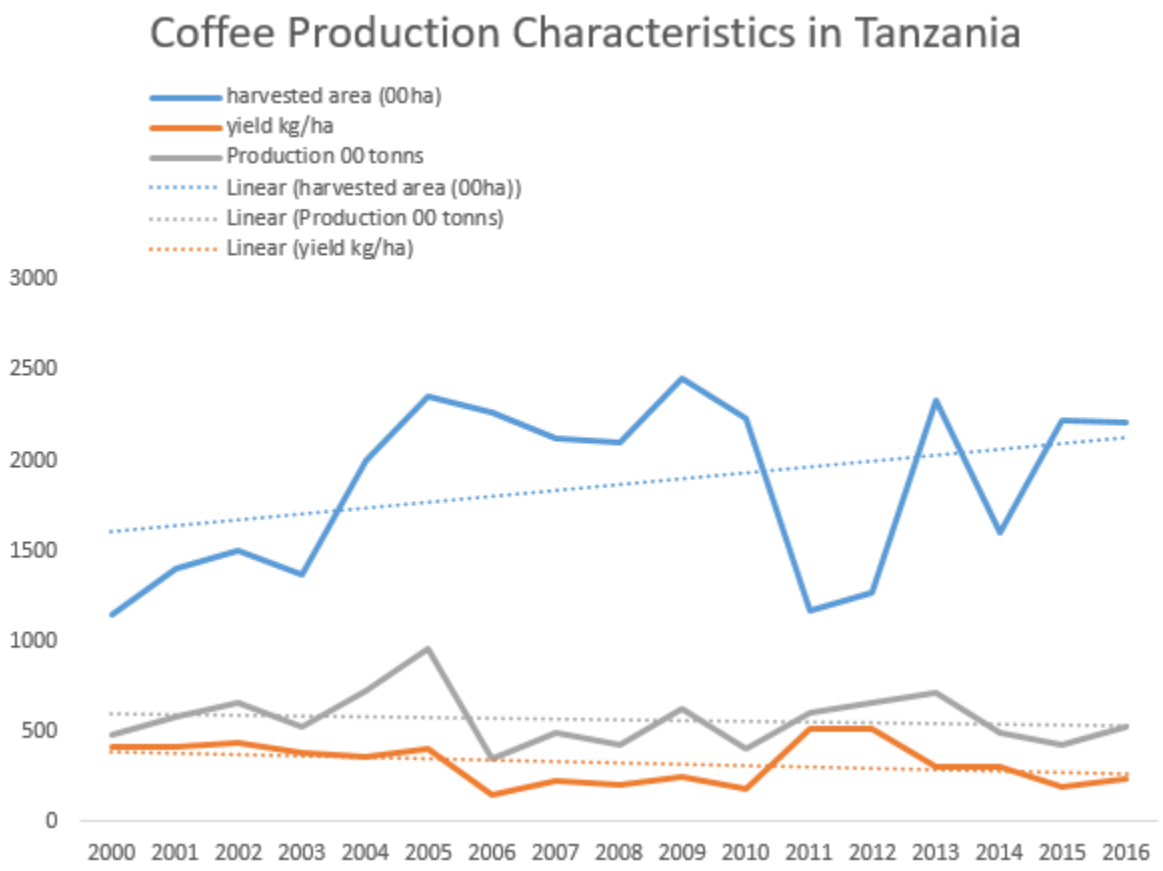

Figure 2: Coffee harvested area, production and productivity trends in Tanzania. Adapted from: FAOSTAT, 2018.

1.1. Research objectives

1.1.1. General objective

To assess and provide a better understanding of the current production situation and identify potential technologies for better coffee production in Mbeya Region.

1.1.2. Specific objectives

(i) Assess current coffee production situation among smallholder farmers.

(ii) Provide an in-depth assessment and understanding of key production constraints accounting for the current coffee yield gap.

(iii) Provide scalable science-based recommendations with high potential of increasing coffee yields.

2. Research Methods and Data Sourcing

2.1. Description of the study site

This research was carried out in three wards; Iwindi, Msia, and Lwati located in Mbeya Region. Mbeya Region is in South West Corner of the Southern Highlands of Tanzania and shares borders with Zambia and Malawi to the South, Rukwa Region to the West; Tabora and Singida Regions to the North; and Iringa Region to the East. The Region is located on Latitude 7.9875° S and longitude 33.4384° E; altitude range of 500-2,981 meters above sea level; annual rainfall ranges of 650-2,600 mm; temperature ranges of 16-25 ^{0}C; and arrange of soil types with volcanic origin[6 7 8 9]. Mbeya is currently among the leading coffee producing regions and has the potential to top production in the country. Farming is the main economic activity of the people and accounts for over 40% of the region's Gross Domestic Product (GDP)[10].

2.2. Primary Data Sourcing

The primary data was obtained through focus group discussions (FGD) held in the three wards. A total of 28 participants were involved: 9 from Msia village; 9 from Iwindi village; and 10 from Lwati village. The discussions were guided by a set of questions around: (a) Causes of yield loss on the farm; (b) Perceived opportunities for yield increase; (c) Barriers of getting access to these opportunities; (d) Current input purchase (and use) behavior; and (e) Priority of coffee inputs if farmers were to be given access.

2.3. Secondary Data Sourcing

The secondary data used were sourced from various scientific publications from recognized and credible journals and research institutions. Other credible websites were also used. Important criteria such as: Coffee varieties and availability; Cropping systems (e.g. coffee spacing, mono-cropping, intercropping); Fertilizer use (e.g. rate, blend, timing and placement); Soil fertility management under coffee plantation (e.g. soil acidity, organic matter, erosion, soil structure); Coffee stress management (e.g. disease, pest, weeds, drought, flooding); and Post-Harvest (e.g. drying, storage, market access) were used. The sourced materials were then downloaded, read and cited as a best practice.

2.4. Data analysis and presentation

Both primary and secondary data were analyzed and validated against each other for better recommendations. The method of data analysis and presentation varied depending on the type of data. Excel 2016 version was used for analysis and presentation of figures.

3. Result and Discussion

3.1. Characteristics of coffee production in Mbeya region

This research confirmed that Coffee is still the most important cash crops accounting for about 39% of land under permanent crops and cultivated by over 80% of farmers in Mbeya Region[10]. From the field visit, it was confirmed that most farmers grow mainly the Arabica variety. The

crop is produced under intensive mixed cropping with maize, beans, and banana dominating the system[12]. Some farmers also practice coffee mono-cropping system, especially those who own large tracts of land. Land owned by household varies between 1-4 hectares, with an average of 0.63 (that vary between 0 and 0.8 hectares) hectares dedicated for coffee production[10]. Farmers were also reported to have low and varying coffee tree numbers (389-1962 plants) and very old trees (average age is about 22 years) in the western and southern parts[14]. The use of soil fertility inputs is not uniform, low and varying depending on the type (organic versus inorganic sources) across the region: A survey by Tanzania Coffee Research Institute reported that only 40% in the south and 2% in west coffee growing zones use inorganic fertilizer. According to our observation, no forms of irrigation was observed to be used for coffee production within the surveyed villages. As a result, the yields were low (about 200-750 kg/ha) under small scale farms [3 16 17].

3.2. Current production challenges and associated yield losses

From the research, coffee farmers in Mbeya were found to face myriad of production challenges that could be largely grouped as policy, climatic, edaphic and socio-economic related factors.

3.2.1. Low adoption of improved varieties and production using old trees:

The research showed that farmers depend on old trees for production. According to Hella and others[14], coffee farmers across the country have trees that are up to 40 years old with slightly younger ones (about 22 years on average) found in the Southern and Western blocks. The old varieties like Bourbon (N.39) and Kents (KP 423) (currently relied on by farmers) do not only represent the low yielding old types but also have lost the genetic potential to yield better and resist diseases, pests, and other climatic conditions[3]. According to Tanzania Coffee Board[20], production using coffee trees that are older than 20 years is no longer profitable. Again, where farmers source for their planting materials was highly questioned during this research. Hella and others again reported that only 1-15% of the coffee farmers were obtaining their seeds from, to some extent, recognized and reliable sources like Research Stations, Estates, Cooperative Unions and Primary Societies. Production of old trees and low adoption of better varieties could be, in parts, due to low access to improved varieties for farmers to adopt. Again, poor extension service and lack of proper campaign to sensitize farmers on these new varieties seriously hinder production.

3.2.2. Poor coffee agronomy and ineffective agricultural extension services:

From the conversations with farmers and visits to various fields, we noticed that most farmers include more than two intercrops with coffee trees- trees and crops like bananas, maize, and beans dominated the list. This observation is not unique as other researchers have also reported similar situation[21]. Such intensive intercropping has been linked with disease attack, high nutrient mining and slow soil warming[22 23]. For instance, banana is considered as an important host for coffee nematode (*Pratylenchus coffeae*) that significantly reduce coffee yields if left

uncontrolled[51]. Also, farmers have low plant densities. For instance, in the Southern and Western parts of the country, farmers are reported to have 389-1962 trees[14]. This is low compared to the recommended optimum range of 3000-4000 trees/ha[25]. All these inadequacies in coffee production could be attributed to the poor and ineffective agricultural extension services in the region. As reported by URoT[10], only about 41% of farming families in the Mbeya Region receive extension services. The larger population are left to learn on their own and apply dangerous practices that could be negatively impacting coffee yields. It was also reported that most of the extension agents offering the services were not trained on Coffee production- some were trained to offer livestock services. This could be a justification as to why most farmers rated low the quality of extension services received in the region[10]. Issues around extension service are governance-related: Inadequate budget allocation to hire more extension officers and fuel cars for movement around during service delivery in the Region. Currently, the extension agent to farmer ratio is about 1:1800[59].

3.2.3. Frequent drought and increasing temperatures:

The declining rainfall amounts received and unpredictable rainfall patterns in Mbeya region and the country as a whole has greatly affected crop production. Farmers are experiencing low rainfall and sometimes droughts that occur during main seasons leading to premature fall of flowers and beans. When asked about the experience, 100% of farmers mentioned drought as key production challenge in the region (**Figure 3**). This is majorly a climate change aspect which has caused shrinkage and redistribution of coffee zones towards the mountain tops[28]. Such low rainfalls are also accompanied by increasing temperatures of +0.30 °C/decade within the producing areas in Tanzania[29]. According to Craparo and others[20], coffee yield loss of about 137 ± 16.87 kg/ha is expected per every 1 ^{0}C rise in minimum temperature in Tanzania. Also, under low rainfall and high temperatures, soil moisture becomes inadequate to allow for proper uptake and utilization of nutrients resulting in high inefficiencies and low yields. **Figure 4** provides a summary of rainfall and temperature characteristics for the last 10 years in Mbeya Region.

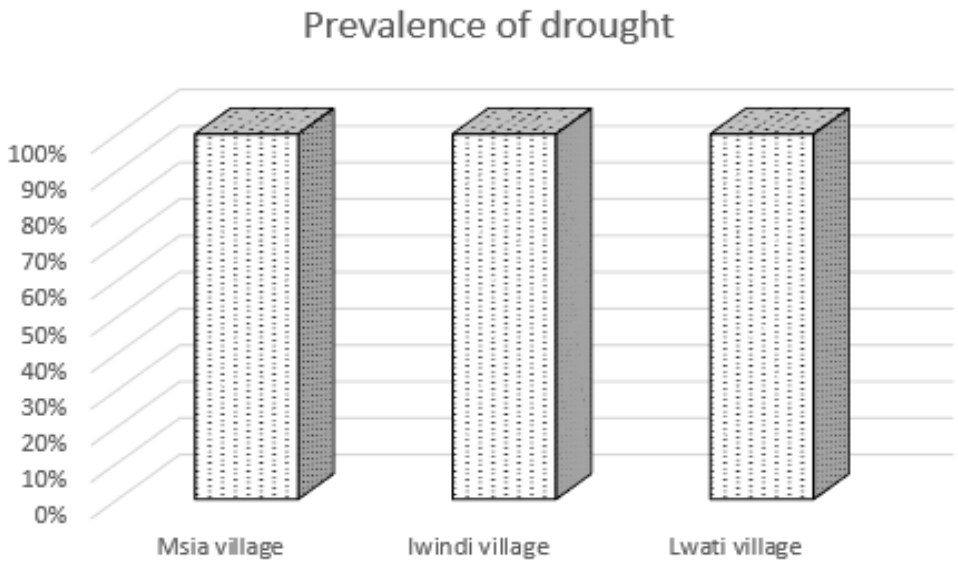

Figure 3: Percentage of farmers who have reported drought as one of the main challenges to coffee production in Mbeya Region

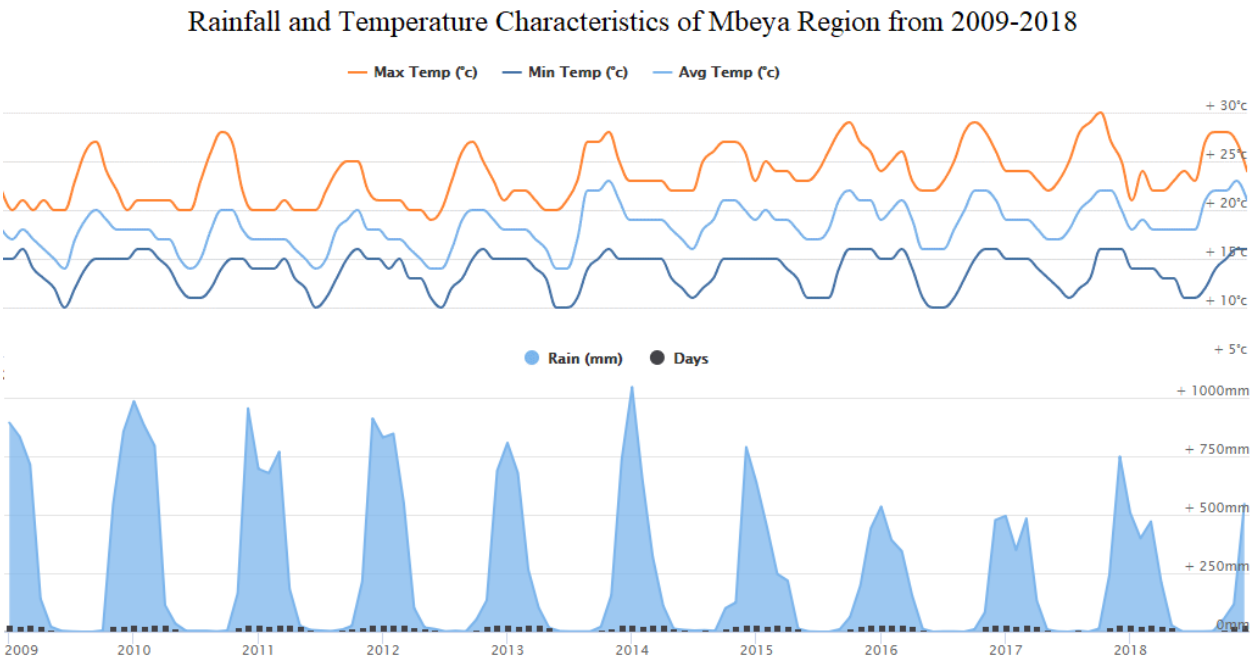

Figure 4: Climatic characteristics of Mbeya Region: Rainfall (mm) and temperature (^{0}C) from 2009 to 2018

3.2.4. Pest and Disease attack:

Research revealed that stem borer (*Monochamus leuconatus*) and berry borer (*Hypothenemus hampei*), Green scale (*Coccus* spp), Antestia bugs (*Antestiopsis* spp) and Mealybug

(*Planococcus kenyae*) are among the most important pests of coffee in the Region. These pests cause significant losses under heavy attack due to direct feeding on coffee stems, flowers, berry and apicals and indirect through transmission and spread of fungal and viral diseases. During this research, farmers could not correctly provide yield losses due the identified pest. However, yield losses of up to 25% (due to stem borer)[60]; 50-100% (due to Coffee berry borer)[61]; and 15-27% (due to Antenstia bugs)[62] have been reported. We observed the attack and 93% of all farmers also reported these pests to be problematic in the region (**Figure 5**).

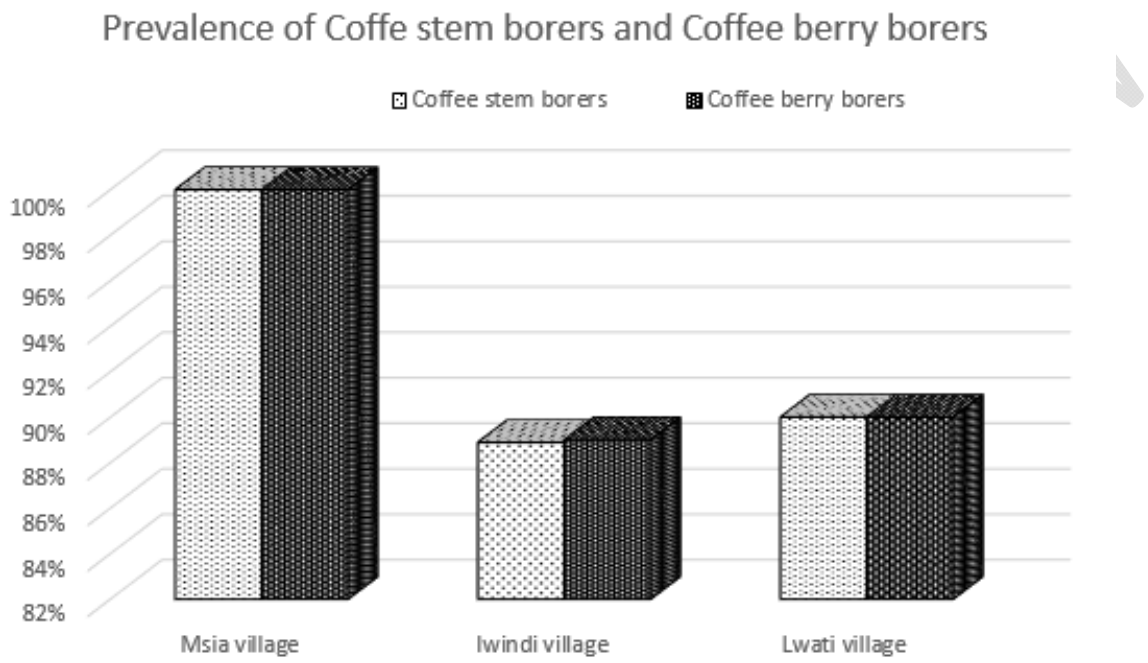

Figure 5: Percentage of coffee farmers reporting presence of coffee stem borer and Coffee berry borer pests on farms in Mbeya Region

On the other hand, our research revealed serious disease infestation: respectively, 86% and 100% of farmers interviewed reported serious yield losses due to Coffee leaf rust and coffee berry disease (**Figure 6**). Other diseases observed include *Fusarium* spp., bacterial blight, and red blister. These diseases cause considerable yield losses in lake zone, south highlands (Iringa, Mbeya, and Rukwa), Ruvuma region and northern zone[21 31]. Yield losses of 35% and 60% due Coffee leaf rust and Coffee berry disease respectively, have been reported[63 64]. Production of less tolerant coffee varieties could be one of the reasons behind the reported yield losses. Lack of credit access and poor coffee agronomy among other reasons hinder proper management of these pests and diseases.

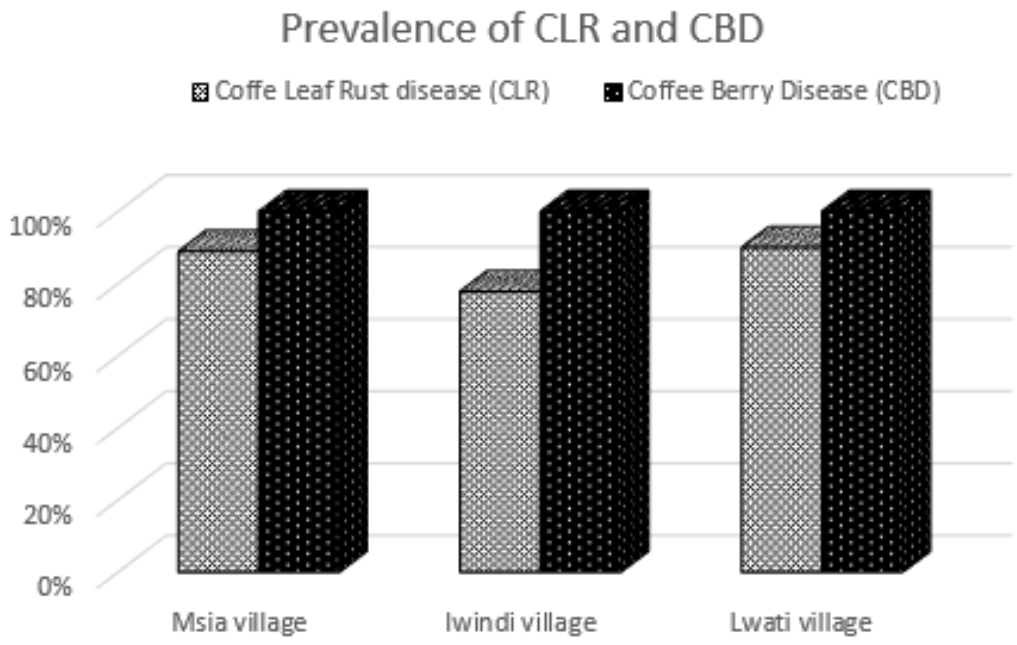

Figure 6: Prevalence of Coffee Leaf Rust and Coffee Berry Diseases as reported by the sampled farmers in Mbeya Region

3.2.5. Soil infertility and low fertilizer use in the coffee zones:

Serious depletion of soil nutrients and deficiencies have been reported in Mbeya Region: Nitrogen, phosphorus, calcium, and Zinc[32], calcium, magnesium, and potassium[33], Copper and zinc deficiencies[34]. Deficiency of these important nutrients cannot allow for the optimal production of coffee. The soils are also acidic, pH <5.5[35]. Such low pH conditions fix further the already deficient nutrients in the forms unavailable for plant use. In an attempt to address the situation, the high cost of fertility inputs hinders farmers' capacity to apply the recommended amounts for better coffee yields. On average, farmers apply about 50 kg of fertilizer per hectare. When asked about fertilizer accessibility and use, 100% of farmers reported that they either use low rates (averaging 1 bag per hectare) or nothing at all for coffee production since the available fertilizers are very expensive. Again coffee extracts a lot of nutrients- It has been reported that for every 1 ton of green coffee bean the plants extracts about 40 kg nitrogen, 2.2 kg phosphorus and 53 kg potassium[36 37]. These nutrients must be replenished yearly to guarantee all-through production.

3.2.6. Poverty and low access to agricultural credit:

Farmers lack access to farm-based financial support to acquire already high priced coffee inputs like fungicides, insecticides, and fertilizers. For instance, 97% of farmers in Kigoma mentioned high prices as a bottleneck to production[21]. Our research confirmed this as 100% of farmers mentioned high fertilizer prices (currently at about Tshs. 65, 000 to Tshs. 90,000 per 50 kg bag)

as a challenge to production (**Figure 7**). This is probably due to low income and high poverty levels. Also, agricultural markets are dominated by a few private traders who are free to practice unfair competition thus burdening farmers with high prices.

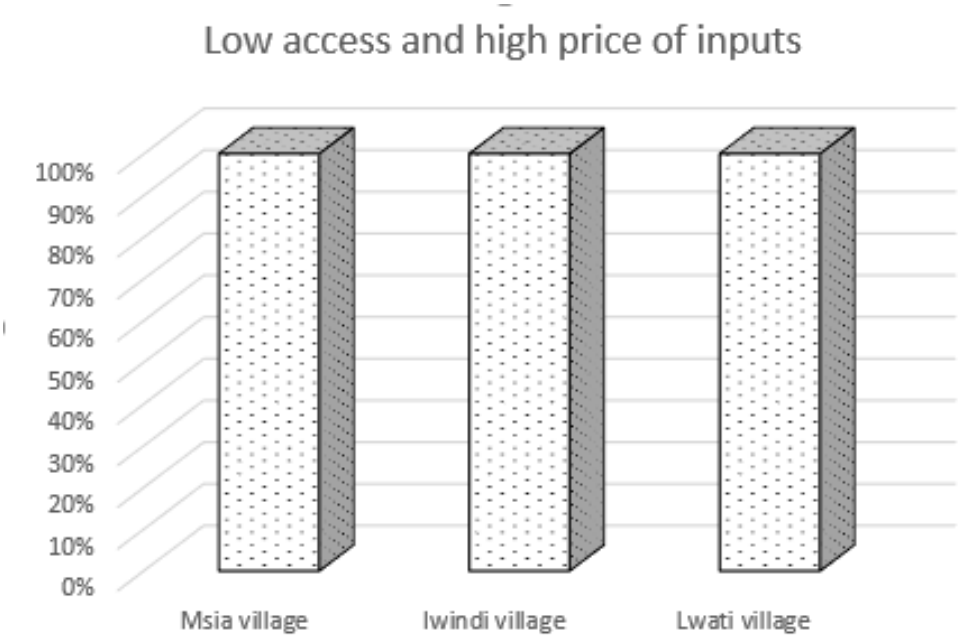

Figure 7: Percentage number of farmers reporting low access and high prices on inputs as one of the main challenges affecting coffee production in Mbeya Region.

3.2.7. Coffee market monopoly and low prices:

This is government related issue. The coffee production is highly regulated by the national government who set the prices. The price set is sometimes influenced by the middlemen leading to low prices. Prices as low as 50-70% of the auction prices have been experienced[21]. When asked about market and price related challenges, 97% of farmers agreed that constantly fluctuating prices and monopoly of the market are serious challenges hindering coffee profitability (**Figure 8**). This could disincentivize farmers to produce the crop. Lack of sufficient market information and knowledge is also one of the factors leading to this level of exploitation. The high cost of transportation due to bad roads and far situated collection and pulpery centers further increase production costs incurred by the farmers.

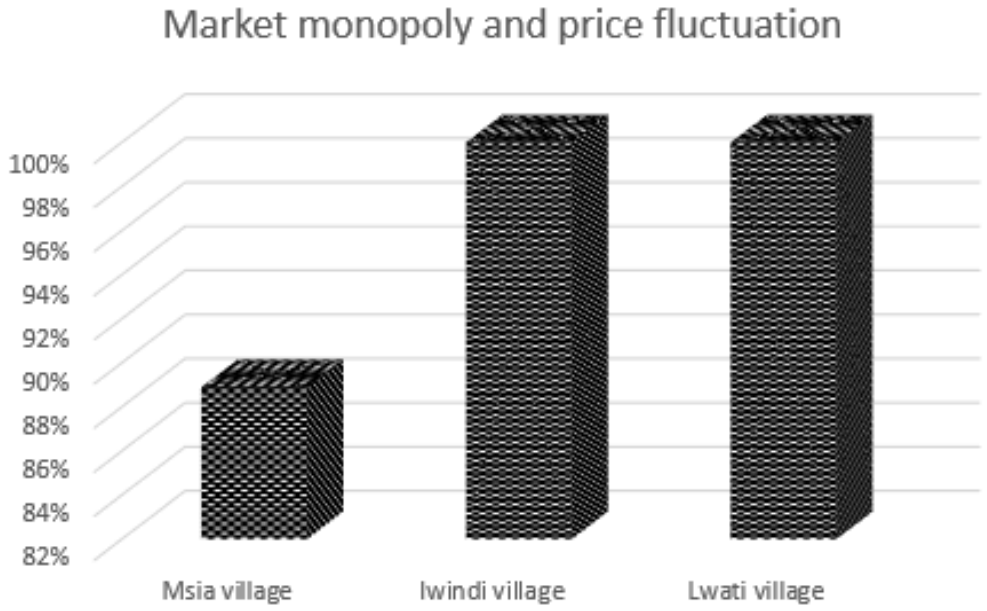

Figure 8: Percentage of farmers who reported that market monopoly and price fluctuation are key factors affecting coffee production in the Mbeya Region

3.3. Available technologies and agronomic practices for improving yields and profitability of coffee in the Mbeya

To manage coffee production challenges, our research focused on available simple technologies with scientific backing that are recommended and adaptable for coffee production in Mbeya Region. High priority was given to preferences mentioned by farmers as their biggest perceived opportunities for yield increase. In the order of priority, farmers listed fertilizer followed by fungicides and pesticides and lastly good quality seedlings as their most important requirements that would ensure increased yields.

3.3.1. Adoption of improved coffee varieties:

Adoption of improved varieties that are ag-zone specific, more tolerant to these pests and diseases and have higher yield potential compared to the current old types grown by farmers should be given priority. Production of improved varieties and young coffee tree would increase profitability of the sub-sector. New varieties like Batian and Ruiru 11 that are fast maturing, high yielding, and tolerant to CBD, CLR and *Fusarium* spp. are available for adoption- more varieties have been released[3 40]. The government should also invest in media campaign and organization of region-wide farmer field days to sensitize farmers on these new releases and the need to change their trees.

3.3.2. Adoption of best coffee agronomy, cropping system, and extension service delivery:

Farmers should be trained to adopt economically viable coffee density- 2500 to 4000 trees per hectare is optimum and could give a better return on investment. Optimum density could be achieved by planting trees at 1.5-3 m by 1-2 m pacing. It is important to consider soil fertility levels and rainfall received when deciding on plant density to use. Better intercropping (with fewer crops) and proper spacing should be encouraged to reduce competition for growth resources like nutrients, light, space, and water. Use of trees with the capacity to fix nitrogen and produce large quantities of mulch (like Grevillea and Lucerne) as windbreaks should be encouraged to help improve soil fertility and soil organic matter. Farmers should be careful when intercropping coffee with fruits trees like mango, macadamia, and guava as they could reduce yields[42]. To avoid over shading and possible quality reduction in coffee, the shades need to be regulated after every 3 years[43]. Famers should work towards replanting their fields with younger coffee trees that have the potential to produce more - young coffee trees yield higher and are profitable compared to those that are older >25 years[12]. Pruning is a very important practice for better coffee production. For even production and steady yield in the following season, it is recommended to prune coffee trees after every harvest; while for changing coffee cropping cycle, pruning should be done after every 6-7 years[45].

3.3.3. Improving soil water conservation and use efficiency:

To respond to frequent droughts experienced, farmers should start by adopting drought-tolerant varieties like Ruiru 11. Multiplication and distribution of such varieties by various players like Research Stations, Estates, Cooperative Unions and Primary Societies could ensure availability for adoption. Farmers should also be encouraged to practice soil and water conservation measures: use of herbicides to control weeds instead of manual hand hoeing helps in minimizing soil disturbances and evapotranspiration[46]. The use of herbicides should be done appropriately and follow instructions provided on the label[47]. Use of plant residues e.g. maize stovers, banana stalks and leaves after harvesting and pruned coffee branches as mulches could help farmers conserve the limited soil moiture[48 49]. During this practice, care must be taken to void using disease infested coffee branches for mulching- they should always be buried deep or thoroughly decomposed before using back in the farmer- to avoid reintroduction of the pathogens.

3.3.4. Improving soil fertility through increased fertilizer use and soil amendments:

Solving soil infertility and low fertilizer use issues should be of high priority looking at the current level of nutrient depletion across the region. Even with the adoption of improved varieties, the inadequate supply of macronutrients and micronutrients would still limit yields. Farmers should, therefore, be encouraged to apply both organic and inorganic fertilizers: Use of organic sources such as manure and compost is important not only for releasing nutrients but also for the amelioration of soil acidity which is currently high. According to Otieno and others[50], SOM form complexes with Al and Fe ions thereby creating conditions that are better for root growth and nutrient absorption. Application of wide quantities of organic materials (0.5-10

t/ha) has been recommended across coffee producing regions depending on soil fertility status, availability of manure and their quality[51 52]. Coffee pulps should not be wasted as they contain nutrients that need to be recycled back to the farms- about 60 kg of coffee pulp is said to contain 1 kg N, 0.60 kg P and 0.9 kg K and other important trace elements[53]. Use of such materials (at 2.5-20 t/ha) as soil amendments has been shown to result in 15-33% coffee yield increase[54]. Nitrogen and potassium are the most extracted nutrients from the soil[55]. Other nutrients are also important and play various crucial roles in the growth and reproduction of coffee as described by YARA International[56]. Application of these inorganic fertilizers should be based on soil analysis and targeted yields. The 4R Nutrient Stewardship principles- the right source, rate, time and method- as described by International Plant Nutrition Institute (IPNI) provides guidance and should be considered for high nutrient use efficiency[57]. According to Hamadi[58], young coffee trees less than 5 months should be supplied with 3.26 gram of Urea, 0.75 gram of Triple Superphosphate and 1.5 gram of Muriate of potash fertilizers per tree from the start, mid and end of the rain season for fast generation of vegetative cover and root establishment. WASI/MARD[59] recommended that about 280 kg N, 100 kg P_2O_5 and 300 kg K_2O per hectare per year be applied to mature and producing trees (above 4 years) to realize 3.5-4 tons of green berry per hectare. For increased nutrient efficiency in fertilizer use, lime should be applied to raise the low soil pH currently experienced in Mbeya region- the rates should be site specific to avoid detrimental effects over-liming.

3.3.5. Coffee pest and disease management:

To manage pests and diseases, better practices should be adopted as early as possible- from proper land preparation and selection of tolerant varieties to direct management of pathogens and pests in the field. During production, scouting and monitoring for pest and diseases should be done regularly to enable early detection and control. Field sanitation, intercropping with legumes (e.g. beans, cowpea) and insect repellents (e.g. N. *tabacum*, L. *camara*, and C. *officinalis*); proper and timely pruning of infested branches and weeding help in controlling these diseases and pests[60].

Controlling stem and berry borers: The bored stems could be sealed with paints or sprayed with kerosene to kill borers inside. Use of parasitoids like *Heterospilus coffeicola* and *Prorops nasuta* provide natural control to the borers[61 62]. Chemical control method has never been reliable due to cryptic nature of the insect (i.e. protected inside the coffee berry), and the availability of coffee berries in the field allowing the survival of the pest from one generation to the next[63]. Several chemicals (including chlorantraniliprole and thiamethoxam) have been recommended for control of borers in coffee[64 65]. Use of any of these chemicals should be done cautiously as guided by Otieno[33].

Green scale, Antesia bug and Mealy bug insects could be controlled naturally through conserving their natural enemies like ladybirds, Tachinid flies, and parasitic wasps[66]. To help this, farmers need to plant more nectar-producing plants as live fences to attract these enemies; and avoid

application of broad-spectrum insecticides that would kill all insects. Use of neem extract has been found effective for these pests[67].

Just like pests, control of diseases would require better field management – weed-free fields, proper and timely pruning of suckers and diseased branches. Adoption of disease-tolerant varieties would always provide the most economical strategy. A number of new varieties such as Ruiru 11, Batian, SC 3, SC 9, SC 11, SC 14 have been reported to be tolerant to most of these common diseases like CBD and CLR[3]. Use of chemicals like chlorothalonil, cyproconazole, flutriafol and cuprous oxide to control CBD, CLR and BBC and other common fungal diseases during coffee growth stages is appropriate[69 70].

3.3.6. Increasing financial and coffee input access:

In order to effectively adopt best coffee agronomy, inputs and training must be availed to farmers. Provision of coffee inputs on loan could be done by microfinance institutions. For instance, One Acre Fund has been successful in providing access to inputs at affordable prices across various countries in Africa[71]. Government subsidy programs could also increase access to key inputs. Formation of farmer groups is also a strategy that could help farmers access large markets and inputs from credit service providers[72].

3.3.7. Improved access to market information and better bargain for better pricing:

There are various organizations buying and marketing coffee in the region- Tembo is one of the popular companies trading in coffee in the region[73]. Together with government involvement, such companies could teach farmers on how to increase coffee quality (better harvesting, drying, and storage methods) for better pricing. By government setting and enacting laws on better coffee bean pricing and quality control, other non-governmental and private players are likely to comply thereby solving this challenge. Such set policies could as well work towards reducing heavy involvement of middlemen in the industry. Organization of farmers into groups and cooperatives could ease the delivery of inputs and services like coffee quality and market information training. Through NGO, Government and private sectors partnerships, farmers could access better market prices and training.

4. Conclusion and Recommendations

From the research, inadequate access to improved seedlings, poor coffee agronomy and low access to extension services, soil infertility, high cost of fertilizer and other inputs, high prevalence of pests and diseases, low access to financial services and poor coffee prices are the main challenges facing coffee production in Mbeya Region. To mitigate the effect of most of these constraints, farmers need to be train on best coffee agronomy and efficient usage of inputs. Provision of financial support was also found to be key. Lack of large primary data sample size and wider geographic distribution of surveyed areas was noticed as a limitation. Again, proper relationship between coffee yield loss as may have been caused by nematode and banana as a potential host need to be evaluated further for better intercropping recommendation.

To help farmers improve on their yields, the following support is required;

i. Provision of training on best coffee agronomy (most important soil water conservation measures, proper and timely weed control, and pruning) and proper use of farm inputs.
ii. Increased access to farm inputs either on credit or subsidy;
    a. Fertilizers- NPK blend with high N and K and urea for topdressing. The application rates of these nutrients should be based on soil analysis results.
    b. Pesticides- majorly for coffee berry and stem borers.
    c. Seedlings- from improved and ag-zone specific varieties.

Declaration

The authors declare no conflict of interest.

Reference

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