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Smallholder palm oil production sector in African countries: State of the art, practices, constraints, and opportunities in Littoral and Centre regions of Cameroon

Lawrence Monah Ndam[1,2], Godswill Azinwie Asongwe[3], Raymond Ndip Nkongho[1,4], Kenneth Mbene[5], Valentine Asong Tellen[1], Emmanuel Jiti Ndi[1], Jun-Jun Ma[6], Aaron Suh Tening[1,2] and Takeshi Fujino [6,7]*

[1]Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea, P. O. Box 63 Buea, South West Region, Cameroon.
[2]Agroecology Laboratory, Department of Agronomic and Applied Molecular Sciences, Faculty of Agriculture and Veterinary Medicine, University of Buea, P. O. Box 63, Buea, South West Region, Cameroon.
[3]Department of Environmental Science, Faculty of Science, University of Buea, P. O. Box 63 Buea, South West Region, Cameroon.
[4]Department of Food Science and Technology, Faculty of Agriculture and Veterinary Medicine, University of Buea, P. O. Box 63 Buea, South West Region, Cameroon.
[5]Department of Chemistry, Higher Teacher Training College of the University of Yaounde 1, P. O. Box 47, Yaounde, Cameroon.
[6]Department of Environmental Science and Technology, Saitama University, Saitama 338-8570, Japan.
[7]Strategic Research Area for Sustainable Development in East Asia, Saitama University, Saitama 338-8570, Japan.

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During palm oil extraction by smallholders in Cameroon, palm oil mill effluent (POME) is generated. A detailed description of the processes involved, aids in reducing loss and minimising the environmental effect of the wastes produced. We characterized herein, the production chain of smallholders' palm oil production in Cameroon. Mixed methods research approach was used, and semi-structured questionnaires administered. Smallholder farmers were adult males (64.4%), married (46.7%) with low levels of formal education (51.1% attained only primary education). Plantation establishment involved the deforestation of pristine vegetation (46.7%). Oil processing was achieved using farmers-owned mills (48.9%) bought at exorbitant prices. Access to finances (51.1%) remained a key limitation to plantation expansion. Workers' health issues abound (75.6%) and were treated using ethnomedicine (31.1%). Sick workers generally paid bills on their own (64.4%). Solid waste was mainly burnt (57.8%) and untreated POME was directed into open pits and streams (37.8%) where they became a nuisance with obnoxious odour and served as breeding grounds for mosquitoes (51.1%). The findings showed that the majority of farmers in the palm oil sector had a deep knowledge base and competence in manipulating the milling machines. Still, government's intervention was needed to stimulate further growth in this important sector.

Key words: Mixed methods research, smallholders, palm oil, characterisation, environmental degradation, sustainability, Cameroon.

INTRODUCTION

Palm oil plays a crucial role in boosting the economy and livelihoods of local communities in many developing producer countries, substantially contributing to poverty reduction and to food security (Chiriacò et al., 2022). Mardiharini et al. (2021) found out that the palm oil industry in the Indonesian oil palm sector can improve the gender equality and inclusivity for creating economically, socially, and environmentally sustainable palm oil supply chains.

Oil palm cultivation on peat lands and cleared forested lands has led to high carbon emissions (Carlson and Curran, 2013), which is a major contributor to global warming. In order to conserve the natural resources, protect biodiversity and reduce the risk of climate change, the palm oil industry must be transformed. Wicke et al. (2011) proposed more research on the use of degraded lands for oil palm cultivation so as to protect the land that still has forest cover.

Palm oil is extracted from the mesocarp (flesh) and endosperm (kernel) of the fruits of the oil palm tree (*Elaeis guineensis* Jacq.), which is native to West and Central Africa. Palm oil has a high content of saturated fatty acids, which makes it suitable for frying and baking, as well as for producing margarine, soap, detergents, cosmetics, and biofuels. Palm kernel oil, which is extracted from the kernel, is mainly used for soap making and other industrial purposes (Rival and Levang, 2014). Palm oil is an essential multipurpose raw material for both food and non-food industries. It is estimated that for every Nigerian household of five, about 2 L of palm oil is consumed weekly for cooking (Ekine and Onu, 2008). It has also been shown from the 2008 Ghana Demographic and Health Survey that one out of every two households (54%) in the country and four out of five (80%) households in the Centre region used palm oil in food preparations (Awere et al., 2022). Small-scale palm oil processing has been shown to be profitable and can also be a source of employment (Ohimain et al., 2014).

According to the Food and Agriculture Organization (FAO), global palm oil production reached 71 million tonnes in 2018, accounting for 37% of the total vegetable oil output. The demand for palm oil has rapidly increased owing to its positive health impacts such as improving brain health, decreasing cholesterol levels, reducing oxidative stress, and improving hair and skin health (Low et al., 2021).

Southeast Asian countries such as Malaysia, Indonesia, and Thailand currently contribute over 85% to the global supply of palm oil (Lokman et al., 2021). Other major producers include Colombia, Nigeria, and Ecuador. Africa as a whole produced 6.3 million tonnes of palm oil in 2018, representing 9% of the global production (FAO, 2020).

The scale of palm oil production in Africa ranges from subsistence production for use within farm families to industrial production, as is the case with the Cameroon Development Corporation (CDC), PAMOL Plantations PLC, and 'Société Camerounaise de Palmeraies' (SOCAPALM), among others. Other authors have divided palm oil production into two main categories, namely, industrial and non–industrial. Industrial production refers to large-scale plantations (>1000 ha) that are owned or managed by multinational corporations or national companies that use modern technologies and inputs to maximize yields and profits, whereas nonindustrial production refers to small- (<10 ha) and medium-scale (10-1000 ha) plantations that are owned or managed by individual farmers or cooperatives that use traditional or semi modern methods and inputs to produce palm oil for subsistence or local markets (Murphy et al., 2021). The state of Cameroon classifies nonindustrial operators in farm sectors as smallholders. In the palm oil production sector, smallholders abound and contribute significantly to meeting the national palm oil needs of the country. However, their characteristics remain largely uncertain. Also, there is massive production of effluent from the palm oil milling process. The characterisitics of this production especially what happens to the effluent depends on the production system and is therefore unique for the production culture of each country. Some systems have developed a zero-discharge approach as reported by Amosa et al. (2013). Such systems pose few environmental health risks, where most of the water is reclaimed, and only bio-treated effluent is released. Ahmad et al. (2006) have also reported systems where palm oil mill effluent is reclaimed for drinking water purposes. This suggests that the faith of palm oil mill effluent depends on the cultural practices around the palm oil production. Such characterization is sparse especially in the smallholder sector in Cameroon where palm oil mill effluent is discharged mainly into freshwater streams and rivers.

Awere et al. (2022) observed the need for the treatment of wastewater produced from palm oil processing activities before disposal. They proposed the exploration of treatment technologies that could achieve recovery of resources (e.g., biogas, compost, and earthworm biomass) and fit into the framework of the circular economy.

The characterisation of palm oil production is essential

*Corresponding author. E-mail: fujino@mail.saitama-u.ac.jp.

to guide government and international policies more effectively. For instance, the understanding of demographic characteristics will provide information on how to direct innovations in agriculture. It has been shown that demographic characteristics play a key role in technology adoption in the corn sector (Fosso and Nanfosso, 2016) and the *Ricinodendron heudelotii* sector in South Cameroon (Mbosso et al., 2015). How these characteristics play out in the oil palm sector in Cameroon is yet to be studied. A major challenge in economies dependent on agriculture is that investments typically do not make commensurate returns. This is especially true in sectors such as the oil palm with long juvenile phases. The understanding of the production, processing, labour, and other cultural characteristics of this sector is essential to better direct resources. It will guide investors in the sector on where to pay more attention. For instance, Ayompe et al. (2021) used an econometric approach to show that there are better profits for investors in selling crude palm oil than for those who market fresh fruit bunches (FFBs). Ayompe et al. (2023) using gray literature, peer-reviewed literature and workshops through Roundtable on Sustainable Palm Oil (RSPO), also found that smallholders face several challenges including weak land tenure rights, the use of poor-quality seeds and low-yielding oil palms, and a lack of skills, expertise, and access to financing. Amugoli et al. (2023) evaluated the challenges and opportunities of oil palm production in Uganda and observed that the industry faces both biotic and abiotic challenges especially in the management of smallholder farmers' field.

Deforestation, soil erosion, water contamination, noise and air pollution, and others, which are inevitable consequences, have all been linked to palm oil production and processing (Qaim et al., 2020; Ogunbode et al., 2022). The disposal of untreated palm oil mill effluent (POME) has led to the enrichment of the drinking water sources with ammonium nitrogen (Tening et al., 2013) and heavy metals (Tening et al., 2014; Ndeh et al., 2022). Accumulation of ammonium nitrogen will lead to algal bloom that will negatively affect aquatic life. Fonge et al. (2011) observed bioaccumulation of heavy metals in fish found in the Douala Estuary of Cameroon. Consumption of such waters could lead to the acquisition of a variety of diseases. Application of bio-organic amended crude POME in maize fields in Cameroon gave higher maize yields with significant increases in soil nitrogen, phosphorus and C-N ratio as compared to the application of inorganic fertilizers (Ngone et al., 2023). It has been shown that composting tends to redistribute heavy metals from more labile forms to more fixed forms which may explain why the application of composts could be useful for heavy metal contaminated lands (Greenway and Song, 2002). While a lot of attention has been paid on the profits of oil palm production, very little information is available on the management of the wastes from the cultivation of oil palm to the production of palm oil especially in the smallholder sector in Cameroon. It is essential therefore to comprehensively characterise the smallholder oil palm sector in Cameroon with respect to waste management so that policy makers can direct resources on areas that would stimulate growth and enhance the relationship between rural communities hosting such palm oil processing units, and the smallholder palm oil mills. This research was aimed at filling this gap, and the findings are significant for a way forward to enhancing smallholders' skills in wastewater purification, POME composting, and biodiversity conservation in the sector through education.

MATERIALS AND METHODS

Reconnaissance survey and ethical clearance

A reconnaissance survey was first carried out to familiarise ourselves with the sites and identify the key actors in the sector. This required meetings with the regional representatives of Agriculture and Rural Development for the Littoral and Centre regions, where information on the nature and organisation of smallholder oil palm plantations was obtained. Key respondents were also identified at this stage to act as contact points and guides during the actual survey. Thereafter, visits were made to the different subdivisions in the two regions where oil palm activity is most intensive, and from the findings of these visits, the sites were selected. Then, ethical clearance was obtained from the Institutional Animal Care and Use Committee (UBIACUC) of the University of Buea, Cameroon, which is the authority for issuing clearances for research of this nature in the South West region of Cameroon.

Study site

The study was carried out in the Centre and Littoral regions of Cameroon. These regions cover the two regions in Cameroon where palm oil production is thriving due to the favourable climate, and represent at least 66% of the palm oil production potentials in the country. In the Centre region, the areas covered included Sombo Village, Sombo Centre, and Nyachou-Pesupal. In the Littoral region, Fiko (Bonalea subdivision) and Nkapa (Dibombari subdivision) of Mungo were covered (Figure 1). The sites selected are known centres of smallholder oil palm cultivation in Cameroon. The Centre region falls within Cameroon's humid equatorial agroecological zone V with bimodal rainfall, whereas the Littoral region falls within agroecological zone IV, which is a humid equatorial zone with monomodal rainfall. The natural vegetation in both zones is tropical forests, with mangroves along the coastlines and riparian fringes. Agriculture is the dominant activity of the inhabitants of the hinterlands in both areas, and the major plantation crop for smallholders is the oil palm. The remaining three agroecological zones are not suitable for oil palm production.

Population and sample size

The study population comprised smallholder farmers in the oil palm

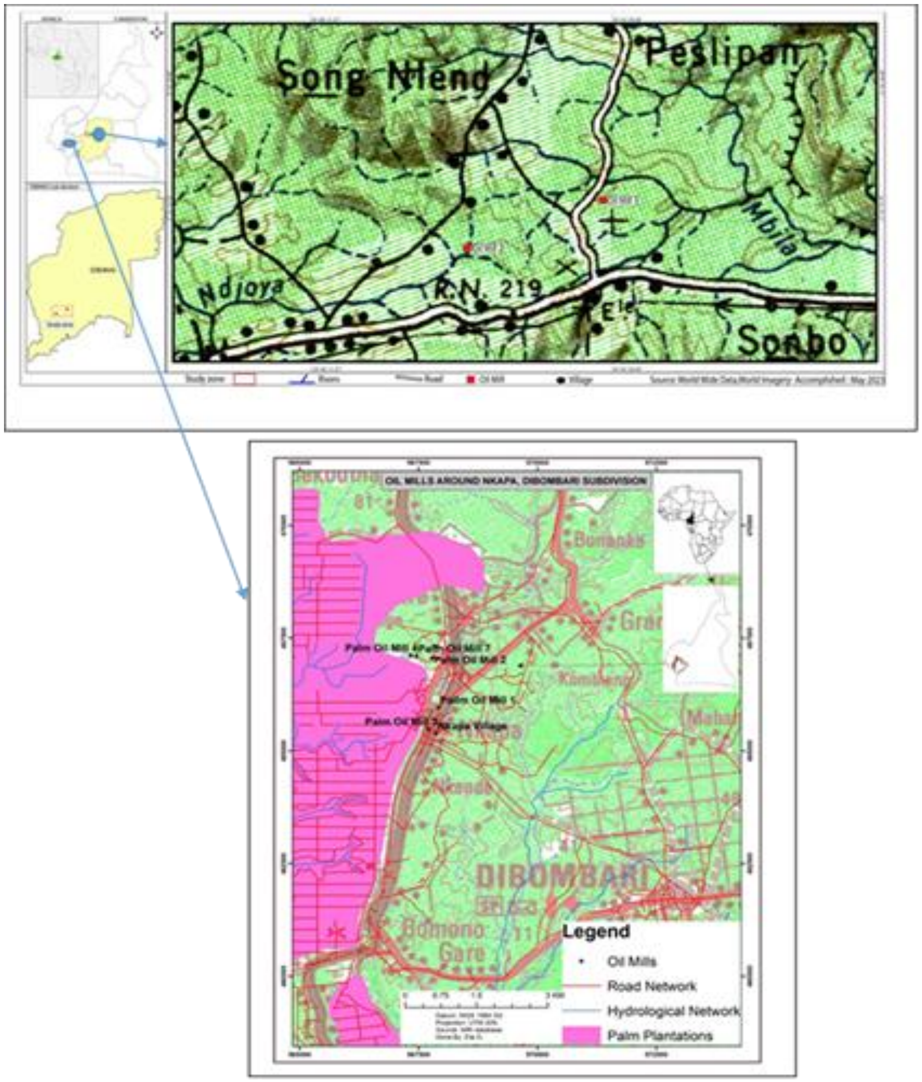

Figure 1. Map showing the distribution of study sites in the Centre (top) and Littoral (bottom) regions.

sector in the Centre and Littoral regions of Cameroon. Based on accessibility, samples were drawn from Sombo village, Sombo Centre, Nyachou-Pesupal, Fiko and Nkapa. A total of 45 respondents were selected for this study on the basis that their plantations satisfied the size criteria for smallholder farms which is farms less than 1000 ha, but also based on their proximity to forests because one of the purposes of the work was to relate findings to environmental health. The respondents were not stratified into farm size, classes or proximity classes.

Approach

Mixed-methods research approaches were applied in this study. Semi-structured questionnaires were administered to 45 respondents selected based on the criteria earlier. The major items of the questionnaire included demographics, oil palm plantations, palm oil processing, land tenure, yield and income, labour and inputs, market access and prices, environmental awareness and practices, and perceived opportunities and constraints.

Observations and ethnography were used to identify and record aspects that would not be covered sufficiently by the items, for instance, modes of disposal of palm oil mill wastes and the different methods of oil processing and storage. Informed consent was obtained from the respondents before administering the questionnaire. Of the 45 respondents all of them completed the questionnaires thus obtaining a response rate of 100%.

Secondary data were obtained by desktop research on palm oil production publications in the University of Buea Library, the FAO statistics yearbook for 2020, and other scientific publications listed in the references.

Statistical analysis

The data generated from the questionnaire were encoded in SPSS Version 21, by binary coding. The data were checked for integrity by outlier analysis and missing value analysis. Subsequently, exploratory descriptive analyses were conducted to identify underlying patterns in responses to the questionnaires. Chi-square test of association was conducted to find relationships between health-related variables like health risks, prevention of health risks, history of health problems, support in promoting hygiene and protection from exposure, etc., for health-relationships; factors affecting yield, methods to manage processing, innovations to increase yield and most common production losses for yield relationships. Factor analysis was carried out to determine spatial associations between the variables, based on their correlations. Where necessary, analyses were conducted at $\alpha = 0.05$.

RESULTS

Demographic characteristics of respondents in the smallholder oil palm sector in the study sites

Results on the demographic characteristics of smallholders in the palm oil production sector in the study sites are presented in Table 1. Majority (64.4%) of the respondents are male and mostly 31 to 40 years old group (33.3%). Most (91.1%) of the respondents have received some form of formal education with a majority (51.1%) having attained primary school education, followed by 31.3% of the respondents: having attained secondary school education. These two groups account for 84.4% of the respondents. Majority (75.6%) of the respondents carry out other income-generating activities and most of them (46.7%) are married. In the sites surveyed, Protestants (66.7%) are the dominant religious group and majority (66.2%) of the respondents have lived in the community for over 10 years with the primary occupation being farming, fishing, or hunting (75.6%).

Smallholder oil palm production characteristics in the study sites

The technical characteristics of oil palm cultivation and harvesting in the study sites are shown in Table 2. Most smallholders (48.9%) have 21 to 30 years of experience in oil palm farming and majority (95.6%) understand that planting is preferably conducted in the rainy season. The typical smallholder farm sizes in Cameroon are 5 ha or less (62.2%), and most smallholders think both Dura and Tenera varieties of oil palm are suitable for planting, and this choice is without guidance from experts (46.7%). For the choice of variety in terms of yield, a majority (80%) of smallholders considered that the Tenera variety is preferable because it yields more oil than the Dura variety. The oil palm tree is typically pruned twice a year for mature palms and three times a year for young palms. The harvest of Fresh Fruit Bunches (FFBs) is low from June to December. High yields of FFBs are observed from January to May (64.4%).

A majority (51.1%) of the respondents obtain their oil palm seeds from IRAD, followed by those who buy from both IRAD and SOCAPALM (17.8%). Other oil palm seed suppliers include Common Initiative Groups (CIGs), Mbongo Company, etc (Figure 2A). For farmers already harvesting, a majority (64.4%) produce between 5 and 8 tonnes of palm oil per year (Figure 2B).

The production process of palm oil from land preparation to the finished product is presented in Figure 3. Oil palm cultivation begins with the establishment of the plantation. The land is cleared, with land preparation activities including slash and burn, felling of trees, and in some cases, levelling or landscaping. Holes are dug in preparation for planting. In some plantations, roads are constructed for easy access. In the meantime, nursery operations commence. Palm seedlings are typically ready for field planting after at least two years in the nursery. Cultural practices include regular clearing, nutrition management and pruning. Harvesting is carried out when the FFBs are ripe and have released some fruits. The FFBs are then prepared for milling, with operations varying depending on the type of mill used. The end product is palm oil of various grades depending on the quality of the process. The waste product includes the FFBs, palm kernels, and sludge from the oil milling process, and these are typically disposed of within the plantation, often near the area of operation (Figure 3).

The production and land tenure characteristics of oil palm production in smallholder plantations in the study sites are presented in Table 3. A majority (64.4%) of the respondents indicated the lack of fertilizer application or nutrition management as the dominant factor affecting production. Other factors mentioned are lack of finances, climate change, birds feeding on palm nuts, and failure to prune the palm trees. Typically, there are no pest management practices (95.6%), and majority (51.1%) do not carry out any sustainable practices such as intercropping. Most (60%) of the farms surveyed were 11 to 20 years old (probably reflecting time from replanting based on field observations), and most farmers (77.8%) gave 21 to 40 years as the economic age for replanting. Majority (93.3%) of the farmers have not been trained in sustainable oil palm cultivation and most of the land used is either rented (31.1%) or bought (40.0%). For those using family land, a majority (62.2%) of such land is owned by adult males in the family. In terms of relief, 44.0% of the respondents reported that their land is flat, whereas the rest reported that their land has either a gentle or steep slope. A majority of the farmers surveyed expressed the desire for more land to expand their plantations.

Deforestation is a major concern in oil palm cultivation in the tropics. A high proportion (46.7%) of the respondents reported that no action is taken to address or mitigate deforestation (Figure 4A). Those who take action carry out intercropping and planting of economically important trees (Figure 4A). Figure 4B shows the distribution of land uses before the oil palm

Table 1. Demographic characteristics of respondents.

Parameter	Frequency	Percent
Sex		
Male	29	64.4
Female	16	35.6
Total	45	100
Age group		
20-30	10	22.2
31-40	15	33.3
41-50	7	15.6
51-60	6	13.3
>60	7	15.6
Total	45	100
Education		
Primary	23	51.1
Secondary	14	31.1
Higher	5	11.1
Vocational	3	6.7
Total	45	100
IGAs*		
Yes	34	75.6
No	11	24.4
Total	45	100
Status		
Single	10	22.2
Married	21	46.7
Free Union	1	2.2
Widow	13	28.9
Total	45	100
Religion		
Catholicism	9	20
Protestantism	30	66.7
Pentecostalism	1	2.2
Islam	5	11.1
Total	45	100
Duration in community		
< 5 years	4	8.9
5 - 9 years	10	22.2
>10 years	28	62.2
Since birth	3	6.7
Total	45	100
Occupation		
Farming / fishing	34	75.6
Trading	1	2.2
Employment	10	22.2
Total	45	100

*IGAs = Income generating activities.

Table 2. Technical characteristics of oil palm production and harvesting.

Parameter*	Frequency	Percent
Level of experience in palm farming		
21-30 years	22	48.9
Suitable planting season		
Rainy season	43	95.6
Farm size		
0-5 ha	28	62.2
Variety grown		
Both dura and Tenera	21	46.7
Reason for choice of variety		
Based on experience	21	46.7
Variety with respect to yield		
Tenera provides higher oil yield than Dura	36	80
Knowledge on improved varieties		
New breed of Tenera from SOCAPALM	17	37.8
No idea	28	62.2
Prunning frequency		
Prune twice a year for old trees, thrice for young	31	68.9
Harvest volumes in relation to months		
Low, June to Dec; medium, none; high, Jan to May	29	64.4
Harvesting equipment		
Both chisel and Malayan knife	26	57.8
Harvesting methods		
Manual	45	100
Harvesting risks		
Accidents, health issues, cost	45	100

*Values in the table for each parameter represent the most frequent responses from the entire set.

plantation establishment. A significant proportion (46.7%) of plantations is established on pristine forest land, whereas the rest have replaced arable croplands and orchards.

Labour characteristics surveyed indicated that most labour in the oil palm sector (data not shown) is drawn from natives (51.1%) and a majority (55.6%) of the farms use family, hired temporary, and hired permanent labour in their operations. Respondents (88.9%) characterised the labour situation in the sector as unstable and 53.3% of them gave seasonal fluctuations as the main reason. The labour force (86.7%) in the oil palm plantation typically lacks social security. Other incentives offered by some smallholders to their workforce include loans (42.2%), housing (28.9%), or both. Smallholders (77.8%) lack access to credit facilities from banks, whereas 22.2% of respondents reported a scarcity of informal finance. All respondents (100%) reported that there is no government financial support; thus, the modes of farm financing include profits from sales of FFBs and palm oil in 17.8%

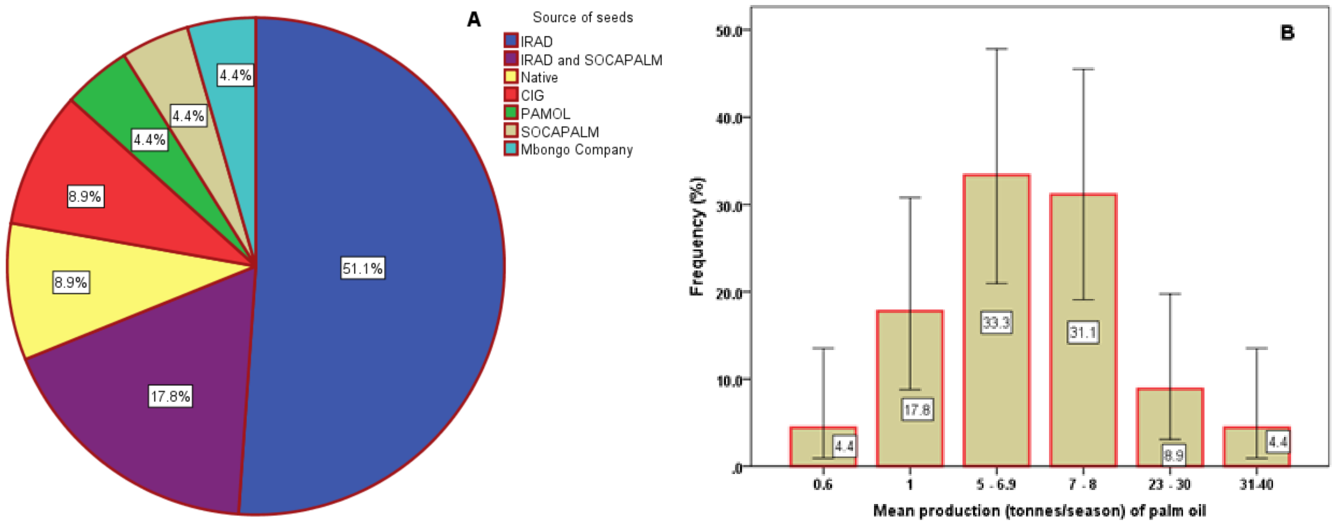

Figure 2. Sources of seeds (A) and mean production of palm oil per season (B) by smallholders in the study sites. Bars represent mean frequencies ± 95% confidence level.

of the respondents and others (82.2%) take care of their own finances.

Transportation and postharvest considerations in the smallholder oil palm sector in the study sites are presented in Table 4. A major challenge to postharvest is the poor state of farm-to-market roads (71.1%), which are generally earth roads that are un-pliable during the rainy season. Fresh fruit bunches are mainly processed within the farmers' own artisanal mills (55.6%) with the rest processed in other artisanal mills. A majority of the FFBs are processed on-farm (66.7%) with the remaining 33.3% sold to intermediaries.

Factor analysis of the correlation matrix between oil palm production characteristics and demographic characteristics of the respondents is presented in Figure 5. The first two factors explain only 30% of the observed variation in the data. From the correlation matrix, there is a strong association between plantation age and the level of experience of farmers on one hand and the ownership of family land, market for FFBs and access to informal finance on the other hand. Similarly, strong associations exist between the age of farmers and their level of education on one hand and among production per season, farm size, modes of farm financing and labour safety on the other hand. Other production and processing attributes sampled, such as labour characteristics, edaphic factors and access to credits are also key determinants whose contribution is not reflected in these results and will require further consideration.

Blue rings indicate variables that are strongly associated; the lengths of the red lines indicate the strengths of the variables within the association; PA = plantation age, LE = level of experience, OFL = ownership of family land, M_FBB = market for FFBs, A_IF = access to informal finance, LH = labour for harvest, PPS = production per season, LS = labour safety, LED = level of education, M_FF = modes of farm financing, RA = replanting age, RAPP = rates of application, FT = fertilizer type, TL = types of labour, AC = access to credit, SP = source of processing, SA = soil amendment, IL = incentives to labour, SFL = source of farmland, FFB_Y = FFB, DC = duration in community, OL = origin of labour.

Palm oil processing

The technical considerations in palm oil processing are presented in Table 5. After harvest, all the respondents (100%) indicated that they store their nuts on a bare floor, and the nuts are separated from the bunches by whole–bunch fermentation, shredding, and re-fermentation (60%). Most farmers (48.9%) use their own mills, bought at 3 million frs cfa (Franc of the Central African Economic and Monetary Community; 1 frs cfa = 600 USD) for 42.2% of the respondents, and most of them considered that the mills would be in service for 5 to 20 years (60%). Most of the mills are neither fully automatic nor fully manual, and 46.7% of them have a capacity to process 1 tonne of FFBs per season. For the most part according to respondents, machine extraction rate and machine age are key determinants of the efficiency of oil extraction, and 64.4% of the respondents reported that the Dura variety is preferred because it produces good-quality oil, whereas others prefer the Tenera variety because it produces more oil. According to 62.2% of the respondents and from field observations, the oil extraction process involves fermentation, boiling of nuts,

Figure 3. Production of palm oil and associated waste generation and disposal in smallholders' farms in the study sites.

Table 3. Oil palm production and land tenure characteristics of smallholders' farms surveyed in the study sites.

Parameter*	Frequency	Percent
Factors affecting production		
No fertilizer application and management	29	64.4
Pest and disease management		
None	43	95.6
Use of sustainable practices		
No	23	51.1
Total	45	100
Age of farm		
11-20 years	27	60.0
Economic age for replanting		
21-40 years	35	77.8
Trained in sustainable production		
No	42	93.3
Source of farmland		
Rented land	14	31.1
Bought land	18	40.0
Ownership of household land		
Male adult	28	62.2
Relief of farm		
Flat	20	44.4
Desire for more land for expansion		
Yes	43	95.6

*Values in the table for each parameter represent the most frequent responses from the entire set.

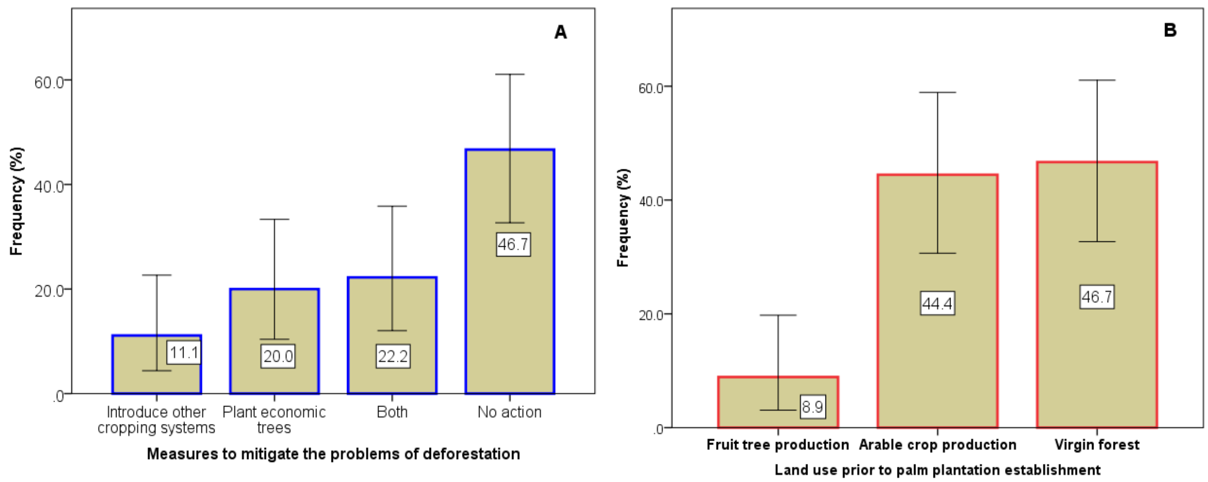

Figure 4. Respondents' perspectives on measures to curb the problems of deforestation (A) and land uses before plantation establishment (B) in Cameroon. Bars represent frequencies ± 95% confidence level.

Table 4. Transportation and other postharvest considerations in oil palm production and management.

Parameter	Frequency	Percent
State of farm roads		
Poor	6	13.3
Bad	32	71.1
Very bad	7	15.6
Total	45	100
Source of processing of FFBs		
Own artisanal mills	25	55.6
Other artisanal mills	20	44.4
Total	45	100
Market for FFBs		
In own mills	30	66.7
Sell to intermediaries	15	33.3
Total	45	100

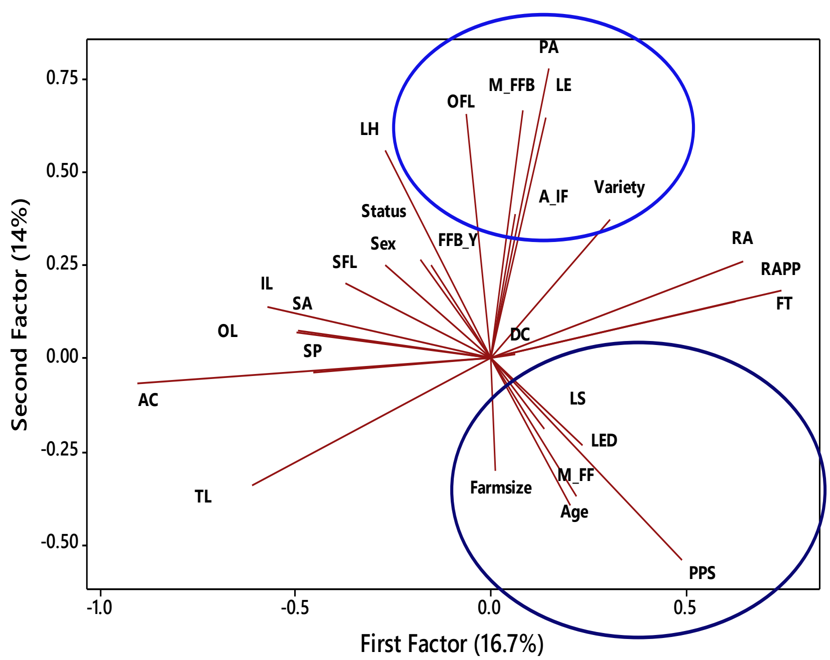

Figure 5. Factor analysis of respondents' demographic characteristics with oil palm production characteristics.

digestion, pressing, clarification, and boiling of the crude palm oil, in this order. According to the respondents, the major challenges in palm oil processing are shown in the following. The FFB weight is based on an estimation, and the fruit and oil burn when water is insufficient (84.4%). Lack of finances remains the major obstacle to the modernization of the process (51.1%). Concerning the palm oil mill effluent (POME) from processing (data not shown), 84.4% of the respondents reported that POME has negative effects on water quality, and 53.3% of the respondents say neighbours complain about the milling process at least sometimes. For quality assurance,

Table 5. Technical considerations in palm oil processing among smallholders in the study sites.

Parameter	Frequency	Percent
Storage method		
Bare floor	45	100
Method of separating nuts		
Whole bunches, fermentation, and shredding 2nd-fermentation	27	60.0
Source of mills		
Bought	22	48.9
Cost of mills		
3 Million	19	42.2
Duration (years) of use		
5-20	27	60.0
Type of mill		
Others	36	80.8
Capacity		
1-ton FFBs (160-200 L oil)	21	46.7
Efficiency factors		
Machine extraction rate	14	31.1
Machine age	17	37.8
Oil characteristics		
Dura produces good-quality palm oil	8	17.8
Tenera yields more palm oil	3	6.7
All	29	64.4
Stages and inputs		
Fermentation, boiling, digestion, pressing, clarification, boiling	28	62.2
Measurement of inputs		
tonnage of FFBs (32 sacks=1 ton), unquantified water, no chemicals	21	46.7
tonnage of FFBs (200 L=1 ton), unquantified water, no chemicals	15	33.3
Challenges and risks		
FFB weight is based on estimation, and fruit and oil burn when water is insufficient	38	84.4
Equipment maintenance		
Use hot water for cleaning without detergent	45	100
Challenges in adopting modern methods		
Lack of finances and maintenance	23	51.1

*Values in the table for each parameter represent the most frequent responses from the entire set.

57.8% of the respondents carry out sensory testing, whereas 13.3% try to prevent moisture from getting into the oil. Factor analysis of the relationships between the demographic parameters and the quality attributes in the milling process (data not shown) did not show any significant association between the demographic parameters, and quality and technical attributes of the milling process.

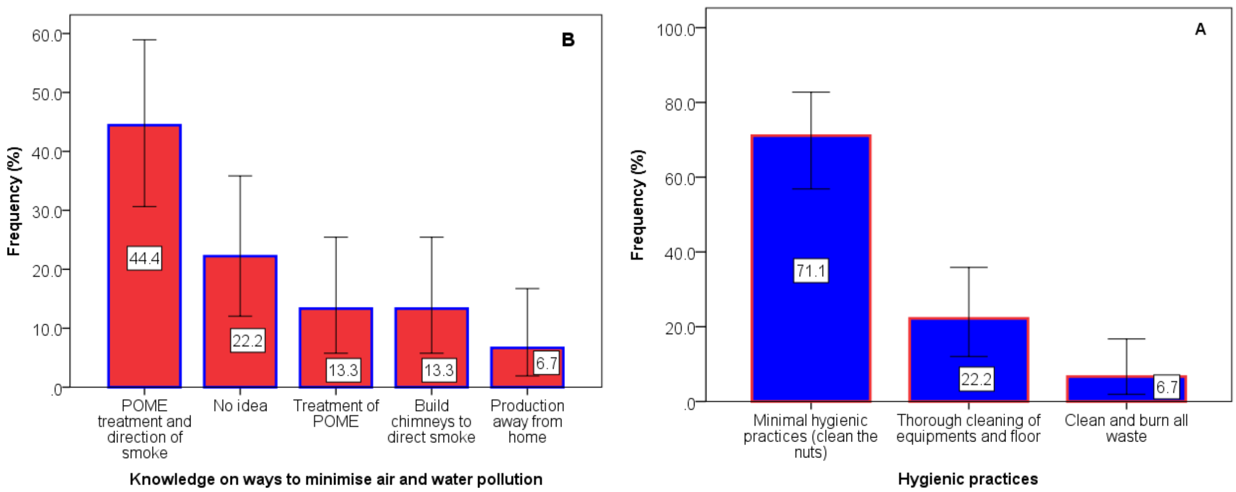

Figure 6. Hygienic practices (A) and knowledge of ways to minimise air and water pollution (B) during the milling of palm oil. Bars represent mean frequencies ±95% confidence level.

Table 6. Health hazards and related attributes in smallholders' oil palm plantations.

Parameter*	Frequency	Percent
Prevention of health risks		
Drink extracts from bitter leaf and pawpaw leaves with milk	14	31.1
History of health problems		
Yes	34	75.6
Regulations and guidelines		
None	43	95.6
Support in promoting hygiene		
Souza council checks on sanitary conditions of workers	27	60.0
Protection from heat and smoke exposures		
Protective clothes and face masks	20	44.4
Payment of workers' bills		
Workers pay themselves	29	64.4

*Values in the table for each parameter represent the most frequent responses from the entire set.

Hygiene and health considerations in palm oil processi

Results on hygienic operations and steps to minimise air and water pollution in smallholder schemes are presented in Figure 6. A majority of the respondents (71.1%) carry out minimal hygiene practices such as cleaning the nuts before processing, and a significant proportion (44.4%) practice POME treatment and have in place mechanisms (chimneys) to re-direct smoke from milling operations.

Table 6 presents the health-related characteristics of the respondents with respect to palm oil processing. To prevent health complications caused by milling operations, most of the workers (31.1%) drink extracts from the bitter leaf (*Vernonia amygdalina*) and leaves of pawpaw (*Carica papaya*) with milk, whereas others (28.9%) practice rotation of workers. Most (75.6%) of the respondents have experienced health problems linked to

Table 7. Pearson Chi-square results showing relationships between health-related variables.

Parameter	Health risks	Prevention of health risks	History of health problems	Support in promoting hygiene
Prevention of health risks	9.246 0.322			
History of health problems	1.820 0.403	18.933** 0.001		
Support in promoting hygiene	8.438* 0.015	11.992* 0.017	9.706** 0.002	
Protection from exposure	13.444* 0.037	9.442 0.665	2.593 0.459	2.649 0.449

Values in the top cell represent $\chi 2$, the Pearson Chi-square test value; values in the bottom cell represent *p*, the level of significance; **$p<0.01$; *$p<0.05$.

processing and 95.6% of them report that there are no health-related regulations and guidelines for the sector. In all the study sites, the Souza Council monitors the sanitary conditions of the workers (60.0%). To protect workers from exposure to heat and smoke, 44.4% of the respondents reported that their workers wear heat-protective clothes and face masks. When workers get ill because of the job, 64.4% of them pay bills on their own, with only 35.6% of the smallholders covering such bills for their workers.

Results of the Pearson Chi-square test of association (Table 7) show that there is a significant association ($\chi 2$ = 8.438, p = 0.015) between health risks and support in promoting hygiene, and between a history of health problems and support in promoting hygiene ($\chi 2 = 9.706$, p = 0.002). A significant association ($\chi 2$ = 13.444, p = 0.037) also exists between health risks and protection from exposure.

Storage of crude palm oil after processing

Palm oil in the sector is mainly stored in closed plastic containers, which are kept clean by most farmers (44.4%) by rinsing with only hot water. There are no regulations for container use, and the benefits of using plastic containers include easy handling (4.4%), no rust contamination (22.2%), and no coagulation (26.7%). All respondents say that the size of a container does not affect oil quality. Table 8 presents the technical characteristics of palm oil storage at the study sites. The main measure to avoid spoilage is to avoid contamination of the oil (44.4%). Transportation from the mill to the storage area involves the use of head loads, wheelbarrows, trucks, and cars. There is no corrosion of storage containers (91.1%) and most farmers (51.1%) monitor the quality of the palm oil during storage. In this monitoring process, majority (68.9%) depend on sensory attributes and a significant percentage (44.4%) take no steps to prevent microbial contamination of palm oil during storage. For those who do, the measures include the removal of water (13.3%), putting oil only in dry containers (20%), and selling immediately (8.9%). There was a strong negative correlation (r = -0.619, p = 0.000) between those who have experienced palm oil spoilage in storage and preventive steps taken against microbial contamination in storage.

Results of factor analysis of the correlation matrix between the demographic characteristics of the respondents and their responses on palm oil storage are presented in Figure 7. The first two factors explain 43.9% of the observed variations in the results. There is a strong positive association between the respondents' level of education with age and measures taken to prevent spoilage. The rest of the demographic parameters did not have any significant association with spoilage-related parameters.

The blue ring indicates variables that are strongly associated; the lengths of the red lines indicate the strengths of the variables within the association; LED = level of education, MPS = measures to prevent spoilage, EPOS = experienced spoilage in storage, DC = duration in community, BSC = benefits of using specific containers, PSM = preventive steps against microbial contamination.

Palm oil yield and yield losses

The factors that affect palm oil yield include the quantity of processing water, mill capacity, and function (15.6%), production season and fermentation duration (17.8%),

Table 8. Technical considerations during storage of palm oil across the study sites.

Parameter*	Frequency	Percent
Measures to prevent spoilage		
Prevent impurity contamination of the oil	20	44.4
Corrosion of storage containers		
None	41	91.1
Monitor quality during storage		
Yes	23	51.1
Quality attributes considered in monitoring		
Sensory qualities	31	68.9
Preventive steps against microbial contamination during storage		
None	20	44.4

*Values in the table for each parameter represent the most frequent responses from the entire set.

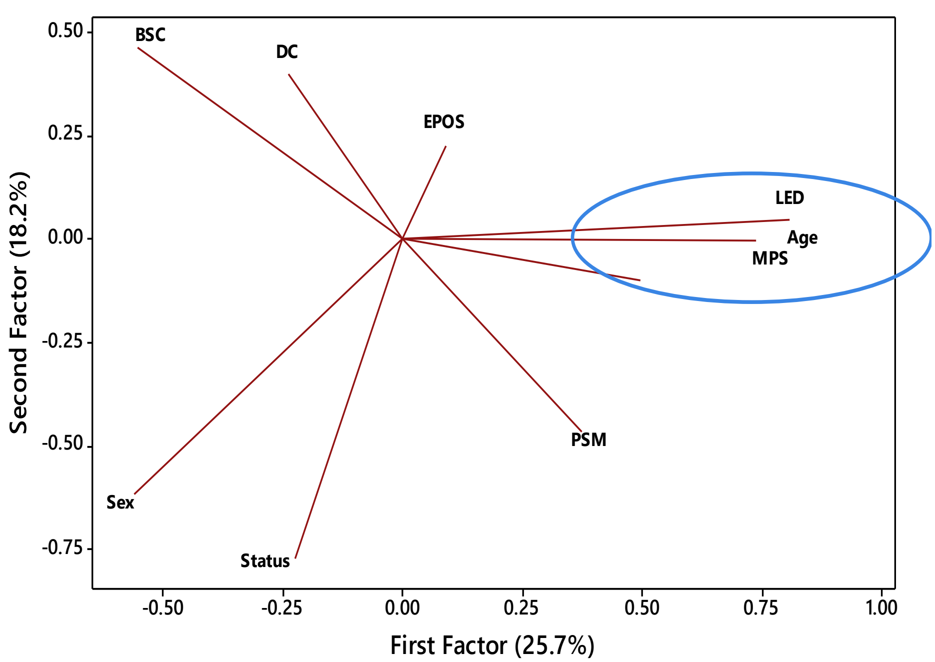

Figure 7. Factor analysis of respondents' demographic characteristics with palm oil storage attributes.

and boiling duration and temperature (15.6%). A majority (82.2%) of the respondents reported that they carried out no innovations to improve palm oil yield. Most common production losses include quality and quantity losses according to 75.6% of the respondents, with 44.4% of the respondents saying there is a 10 to 18% loss due to poor harvest. According to 35.6% of the respondents, one major implication of yield losses is reduced income, and 62.2% of the respondents practice tree planting to mitigate deforestation (Table 9).

Results of Chi-square ($\chi2$) tests of association of yield and yield loss parameters are presented in Table 10. There was a strong association between the factors affecting palm oil yield and methods to manage

Table 9. Characteristics of production and yield losses in smallholders' plantations.

Parameter*	Frequency	Percent
Most common production losses		
Quality and quantity losses	34	75.6
Percentage loss due to poor harvest		
10-18%	20	44.4
Implication of yield losses		
Low income	16	35.6
Support to improve yield		
None	45	100
Balance yield and sustainability		
Minimal sustainable practices (tree planting)	28	62.2
Weather patterns and yield		
High rainfall reduces quality and causes erosion	14	31.1
Factors for sustainable production and yield		
Access to finances, good quality nuts, and processing facilities	10	22.2

*Values in the table for each parameter represent the most frequent responses from the entire set.

Table 10. Pearson χ2 test of association showing relationships between yield and oil losses-related variables.

Parameter	Factors affecting oil yield	Method to manage processing	Innovations to increase yield
Method to manage processing	**70.696**** **0.000**		
Innovations to increase yield	**13.237*** **0.010**	**45.000**** **0.000**	
Most common production losses	8.517 0.074	**13.822**** **0.008**	3.148 0.076

Values in the top cell represent χ2, the Pearson Chi-square test value; values in the bottom cell represent *p*, the level of significance; $^{**}p<0.01$; $^{*}p<0.05$.

processing (*χ2 = 70.696*, *p* = 0.000). A significant association was observed between the factors affecting palm oil yield and innovations to increase yield (*χ2 = 13.237*1, *p* 0.010). Similarly, there was a significant association between the methods to manage processing and innovations to increase yield (*χ2 = 45.00*, *p* = 0.000). The relationship between the most common production losses and methods to manage processing was also significant (*χ2 = 13.822*, *p* = 0.008).

Other factors involved in oil palm production include production costs, marketing and price fluctuations, customary and traditional issues especially land disputes with local authorities (37.8%), and conflicts with development projects by the government on customary lands (57.8%).

Issues on palm oil production wastes

Table 11 presents issues related to palm oil production

Table 11. Oil palm waste and its management.

Parameter*	Frequency	Percent
Management of empty fruit bunches		
Burning	27	60
Destination of liquid mill waste		
Directed into a pit	17	37.8
Management of solid waste		
Burning	26	57.8
Challenges in collection and transport of waste		
Bad roads	16	35.6
Palm oil effluent		
Liquid waste from FFBs	24	53.3
Variation in impacts of palm oil effluent		
More FFBs processed, more POME	24	53.3
Impact of palm mill effluent		
Nuisance and mosquito breeding grounds	23	51.1
Steps to mitigate environmental impacts of effluent		

*Values in the table for each parameter represent the most frequent responses from the entire set.

waste. Most of the empty fruit bunches produced (60%) are burnt and respondents direct POME into pits (37.8%) and streams (20%). Solid waste is mainly burnt, and the major challenge in the collection and transportation of waste is bad road networks (35.6%), with most respondents (40.0%) facing a combination of challenges including the high cost of transportation and shortage of land to dig pits.

Environmental issues related to POME are presented in Table 11. POME (53.3%) constitutes a major waste from the production chain. As more FFBs are processed, more POME will be produced (53.3%). A major impact of palm oil mill effluent is the nuisance and the creation of breeding grounds for mosquitoes (53.3%). A majority of the respondents (68.9%) take no action to mitigate the environmental impacts of palm oil mill effluent. Other observations include the production of smoke and its being a nuisance to neighbours, effluent and solid waste dumps that act as breeding grounds for mosquitoes and other pests, as well as odor pollution.

Results of factor analysis of demographic characteristics and environmental, customary, and legal issues are presented in Figure 8. The first two factors contribute 25.3% to explaining the observed variation in the data. There are no clear associations between the different parameters. This is a very low level of association indicating that more factors not considered in this study may be contributing to the observed variation.

The lengths of the red lines indicate the strengths of the variables within the association; LED = level of education, LTOP = land tenure and the oil palm industry, IS = indicators of spoilage, BPQ = brand names and palm oil quality, CMLF = customary and modern legal frameworks, CPW = compensation modes for palm work, CCTW = challenges in collection and transportation of waste, EPO = how to ensure purchase of oil, CH = cost per hectare, TIS = technology, innovation, and safety, DC = duration in community, MSW = management of solid waste, IME = impact of palm mill effluent, RWP = health risks of working in processing, UP = main uses of palm oil, UEF = use of empty fruit bunches, APM = sustainable alternative production methods, SSILP = social sustainability and improved labour practices.

DISCUSSION

This study revealed that the smallholder oil palm sector in Cameroon is dominated by adult males, mostly married with a significant household size. These characteristics

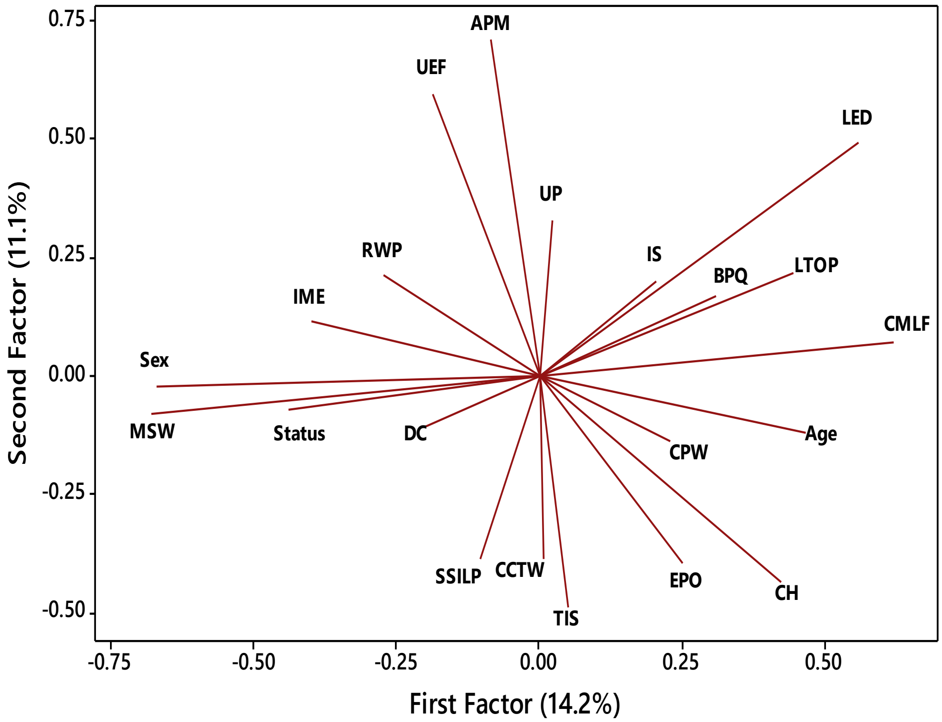

Figure 8. Factor analysis of associations of respondents' demographic characteristics with labour, uses, and cultural and legal considerations.

could in part be expected because this is the age bracket of responsibility, wherein the needs of life and family challenges require the men to provide. Cultural aspects are also in play here, especially when it concerns land tenure systems, which culturally favour males over females (Chigbu, 2019). The oil palm agribusiness, being land-intensive, requires somebody with access to land to establish, and males fit this profile, as reported by de Vos and Delabre (2018) and Mehraban et al. (2022). Indeed, cultural land tenure systems in Cameroon favour men over women in terms of ownership inheritance of land, and our findings corroborate those of Fonjong and Gyapong (2021), and suggest that for the most part, the smallholder oil palm plantation sector in Cameroon will remain male-dominated for quite a while. The present findings also hold promise for increasing gender diversification in the sector, considering the significance though not a dominant proportion (35.6%) of female participation in the smallholder oil palm sector. Ayompe et al. (2021) have shown that in Cameroon, land ownership is an important parameter that determines profitability in the oil palm sector. A significant demographic finding of note is that a majority of the respondents have attained at most secondary school education. Typically, the less educated find themselves employed in agriculture, which is a very knowledge-intensive sector. This is especially challenging where there is a need for comprehension of deeper issues such as how the sector affects the environment. The high pollution rate of water and soils, which have been reported by Tening et al. (2013), Tening et al. (2014), Ndeh et al. (2022), and Fonge et al. (2011) could partly be due to this low level of education of the oil palm farmers in these regions as revealed by the demographic results. Harvey et al. (2014) also associated the extreme vulnerability of smallholder farmers to agricultural risks and climate change with the limited capacity of the farmers. Subsequently, we attempt to assess the relationship of demographic strata with oil palm production and processing variables.

Most smallholders in the oil palm sector in Cameroon have over 21 years of farming experience, which is correlated with their appropriate variety selection and knowledge of key parameters, such as when to plant in new fields, the economic lifespan of the plantations, pruning frequencies, and perception of farm-related risks among other technical considerations raised. Fosso and Nanfosso (2016) have shown that farmers' age, education, and farm sizes are key determinants in the adoption of agricultural innovations in the West region of Cameroon, which is consistent with the findings of Mbosso et al. (2015) in Southern Cameroon. Indeed, factor analyses of the correlation matrix in terms of oil palm production characteristics in the study sites indicate that the farmers' level of education, level of experience in the farm, and farmers' age are key determinants of environmental protection, access to farm finances, production per season, and labour safety in the plantations.

State research institutions and parastatal oil palm production enterprises are pre-eminent to the survival of smallholder oil palm producers in the study sites; IRAD, SOCAPALM, and PAMOL jointly provide over 75% of the seeds for plantation establishment by smallholders. The present study suggests a need for continued state support for the oil palm sector and shows that the state has been instrumental in some way to the growth observed in the sector. Improved palm seeds are expensive compared with the palm oil output per season. It is clear that few smallholders have the capacity for high palm oil output, but cost considerations of improved seeds could be an issue as is the case with other innovations (Ahmad et al., 2006). Indeed, our findings indicate that a majority of the respondents experience a limited output, which they attribute to the lack of finances, failure to apply fertilizers, and failure to prune palm trees. The latter could be in some way related to the lack of finances for the sector.

In the production chain for oil palm, deforestation is always present; distribution of land uses before plantation establishment shows that about 47% of smallholder oil palm plantations surveyed have replaced pristine forests. Land clearing is an indispensable step in oil palm plantation establishment because the seedlings are poor competitors for light (if shaded) and nutrients (if crowded with weeds or other plants). Alternative planting solutions that do not involve deforestation are rare. The FAO suggests that oil palm contributes 5% to tropical deforestation, whereas the European Commission revealed that oil palm contributes 2.3% to global deforestation. The negative effects of tropical deforestation on climate change, water resources, soil erosion, and public health have been well established (Lawrence et al., 2022). The dominant proposed measure in the face of deforestation is mitigation, and our findings show that over one-third of the respondents mitigate deforestation by planting economic trees and adopting cropping systems that could act as net sinks for carbon; this is a popular solution in the face of deforestation and climate change (Osman et al., 2023).

Palm oil processing is a key step for upscaling profits from the enterprise, as sales of crude palm oil earn far more profits than that of FFBs (Ayompe et al., 2021). Like all other crops, processing adds value to the produce and crude palm oil sells for more because it has multiple uses in culinary, cosmetic, chemical and confectionary industries, just to name a few. Through this survey, we have ascertained the state of smallholder processing in the study sites, which are artisanal at best. Although the farmers demonstrate deep knowledge of the milling process, they report that lack of finances remains a key challenge in the sector. The cost of acquiring an artisanal mill of reasonable capacity is high, and so the adoption rate of innovations in this regard has been low, consistent with the findings of Mbosso et al. (2015).
nge in the sector. The cost of acquiring an artisanal mill of reasonable capacity is high, and so the adoption rate of innovations in this regard has been low, consistent with the findings of Mbosso et al. (2015).

During processing, some hygiene and health considerations are necessary. The oil palm sector is fraught with health hazards that range from possible accidents and physiological diseases (Henry et al., 2013). This is due to exposure to agrochemicals especially herbicides, heat shock, and burns during milling processes as well as musculoskeletal injuries from lifting heavy weights in the course of palm oil packaging and storage. This is consistent with the findings of Myzabella et al. (2019). The present findings indicate that a majority of the respondents clean their nuts to a certain degree before processing, but this is challenging especially in larger–scale smallholdings. Another consideration is the treatment of the milling effluent, which can be the breeding ground of disease vectors such as the Anopheles mosquitoes that transmit the malaria parasite. Such a treatment would reduce malaria incidence among the workers and surrounding inhabitants. To prevent health–related complications from the palm plantation work, workers drink extracts of *V. amygdalina* and *C. papaya* leaves with milk, practice worker rotation, and wear protective clothing. Extracts of *V. amygdalina* and *C. papaya* are popular ethnomedicines in most parts of Africa, known for their efficacy against malaria, hypertension, diabetes, and other health conditions (Hariono et al., 2021; Ugbogu et al., 2021). However, workers (75.6%) still become ill, and when this happens, a majority of them have to pay bills on their own. There is little or no social security in the smallholder plantation sector in Cameroon. Nationwide, the use of health insurance is not mandated, and existing schemes are still in their infancy. There is little support for smallholders for promoting hygiene, and correlation analysis revealed that if this support were provided, health risks would be minimised.

Plastic containers of various sizes are used to store crude palm oil and farmers mainly consider their ease of use and the lack of possible rust contamination as the criteria for selecting them. Other considerations include avoiding spoilage during storage through regular monitoring, and this depends directly on the age of the farmer and the level of education, consistent with the findings of Fosso and Nanfosso, (2016) on the importance of these demographics in the farming sector.

Management of waste from palm oil production operations is essential for neighbours to accept these artisanal mills within their vicinities. This is an issue of concern in several other countries where palm oil is produced. Deforestation, solid waste disposal, palm oil mill effluent, related odour pollution, and others are noted in the study sites, prompting most neighbours to complain at least sometimes. Qaim et al. (2020) reported similar findings in a review of works from several Asian countries. Similar findings have been reported across several plantations in East Kalimantan (Anwar et al., 2014), which point to the fact that at the artisanal level, smallholders usually lack the financial and technological needs for effective palm oil waste management, waste valorization, or palm oil mill effluent disposal are beyond the financial means of the smallholders. Most smallholder oil palm farmers reported that they lack access to both formal and informal financing.

The main essence of oil palm plantations is the production of crude palm oil, either for direct domestic use or for further processing in industries. Therefore, minimizing production and processing losses is essential. The present findings have revealed various factors that decrease oil yield, including the quantity of water used, mill capacity, production season, fermentation duration, boiling duration, and temperature. Efficient management of these processes is directly related to the farmers' experience and level of education. There were strong negative correlations between factors affecting palm oil yield and the adoption of innovations to increase yield, and between the adoption of methods to manage palm oil processing and most common production losses. This further highlights the importance of demographics in postharvest yield and losses (Nchanji et al., 2016). This fact was supported by Rao et al. (2023), who outlined the state-of-the-art crop management and processing of palm oil in India, which is considered as the future crop. These results are essential for policymaking in the sector. Governments and other state and non-state actors can appropriate these results, in improving the sector, for example further education of farmers in farmer field schools would improve effluent treatment and discharge processes, while creating better access to land and related resources through exploitation of the provisions in the land tenure laws.

Conclusion

In this study, we have characterised the smallholder oil palm production sector in Cameroon. We found that the demographic characteristics of the population affected only a few of the production, processing, storage, and other parameters examined in this study. The sector is rich in manpower with skills in handling the milling machines. However, it is plagued by poor access to land and finances and the lack of state intervention in key areas. Employees' health and safety to environmental pollution remain key concerns, as are problems of waste management in the sector. Waste management issues are directly linked to access to finances and state intervention. These results provide a framework for better policymaking in the sector. It is recommended that specific programmes for the smallholder oil palm sector that currently exist under the Ministry of Agriculture and Rural Development should be scaled up. The education of smallholders as well as financial assistance to modernise processing should be encouraged. These would go a long way to jumpstart the sector by enhancing the sustainable use of the environment, profit margins, and consequently, the Gross Domestic Product (GDP) contribution from the oil palm sector. Further studies are needed to establish, for instance, the effectiveness of government initiatives in the sector, clarifying channels of distribution and marketing of palm oil to improve farmers' profit margins. Studies are also needed to assess the environmental impacts of palm oil effluent from smallholder mills in Cameroon, to propose appropriate and applicable solutions in the sector.

CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest.

ACKNOWLEDGEMENTS

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REFERENCES

Ahmad AL, Chong MF, Bhatia S, Ismail S (2006). Drinking water reclamation from palm oil mill effluent (POME) using membrane technology. Desalination 13:35-44.

Amosa MK, Jami MS, Muyibi SA, Alkhatib MFR, Jimat DN (2013). Zero liquid discharge and water conservation through water reclamation and reuse of biotreated palm oil mill effluent: A review. International Journal of Academic Research 5(4):169-182.

Amugoli MO, Bwayo Masika F, Asiimwe A, Ddamulira G (2023). Challenges and Opportunities of Oil Palm Production in Uganda. IntechOpen, doi:10.5772/intechopen.108008.

Anwar R, Sitorius SRP, Fauzi AM, Widiatmaka M (2014). Technical culture and productivity of oil palm in several plantations in East Kalimantan. International Journal of Latest Research in Science and Technology 3(2):19-24.

Awere E, Bonoli A, Obeng PA, Pennellini S, Bottausci S, Amanor WK, Akuaku EK (2022). Small-Scale Palm Oil Production in Ghana: Practices, Environmental Problems and Potential Mitigating Measures. In: VY Waisundara (ed.), Palm Oil-Current Status and Updates pp. 91-100, IntechOpen, DOI:10.5772/intechopen. 106174.

Ayompe LM, Egoh BN, Nkongho RN, Wandum LM, Orang BO, Fiaboe KKM, Tambasi EE, Kettunen M (2023). Complexities of sustainable palm oil production by smallholders in sub-Saharan Africa. Sustainable Development pp. 1-13. DOI: 10.1002/sd.2674. wileyonlinelibrary.com/journal/sd.

Ayompe LM, Nkongho RN, Masso C, Egoh BN (2021). Does investment in palm oil trade alleviate smallholders from poverty in Africa? Investigating profitability from a biodiversity hotspot, Cameroon. PLoS ONE 16(9):e0256498. https://doi.org/10.1371/journal.pone.0256498.

Carlson KM, Curran LM (2013). Refined carbon accounting for oil palm agriculture: disentangling potential contributions of indirect emissions and smallholder farmers. Carbon Management 4(4):347-349.

Chigbu UE (2019). Anatomy of women's landlessness in the partilinear customary land tenure systems of sub-Saharan Africa and policy patway. Land Use Policy (86):126-135.

Chiriacò MV, Bellotta M, Jusić J, Perugini L (2022). Palm oil's contribution to the United Nations sustainable development goals: outcomes of a review of socio-economic aspects. Environmental Research Letters 17(6):1-22. DOI: 10.1088/1748-9326/ac6e77.

de Vos R, Delabre I (2018). Spaces for participation and resistance: gendered experiences of oil palm plantation development. Geoforum 96:217-226.

Ekine DI, Onu ME (2008). Economics of small-scale palm oil processing in Ikwerre and Etche Local Government Areas of Rivers State, Nigeria. Journal of Agriculture and Social Research 8(2):1-9. DOI: 10.4314/jasr.v8i2.43342.

FAO (2020). World Food and Agricuture Statistical Yearbook [Online]: Available at www.fao.org

Fonge BA, Tening AS, Egbe EA, Awo EM, Focho DA, Oben PM, Asongwe GA, Zoneziwoh RM (2011). Fish (*Aruis heudelotii* Valenciennes, 1840) as bio-indicator of heavy metals in Douala estuary of Cameroon. African Journal of Biotechnology 10(73):16581-16588.

Fonjong LN, Gyapong AY (2021). Plantations, women, and food security in Africa: Interrogating the investment pathway towards zero hunger in Cameroon and Ghana. World Development 138:105393-105407.

Fosso P, Nanosso T (2016). Adoption of agricultural innovations in risky environment: the case of corn producers in the west of Cameroon. Review of Agricultural, Food and Environmental Studies 97:51-62. 10.1007/s41130-016-0008-3.

Greenway GM, Song QJ (2002). Heavy metal speciation in the composting process. Journal of Environmental Monitoring 4:300-305.

Hariono M, Julianus J, Djunarko I, Hidayat I, Adelya L, Indayani F, Auw Z, Namba G, Hariyono P (2021). The Future of Carica papaya Leaf Extract as an Herbal Medicine Product. Molecules 26(22):6922-6939. DOI: 10.3390/molecules26226922. PMID: 34834014; PMCID: PMC8622926.

Harvey CA, Lalaina RZ, Nalini SR, Radhika D, Hery R, Hasinandrianina RR Rajaofara Haingo R, MacKinnon JL (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. Philosophical Transactions of the Royal Society, pp 130089-130106.

Henry LJ, Esfehani AJ, Ramil A, Ishak I, Justine M, Mohan V (2013). Patterns of work-related musculoskeletal disorders among workers in palm plantation occupation. Asia Pacific Journal of Public Health 27(2):NP1785-NP1792. DOI: 10.1177/1010539513475657.

Lawrence D, Coe M, Walker W, Verchot L, Vandecar K (2022). The Unseen Effects of Deforestation: Biophysical Effects on Climate. Frontiers in Forestry and Global Change 5:756115-756115.

Lokman NA, Ithnin AM, Yahya WJ, Yuzir MA (2021). A Brief Review on Biochemical Oxygen Demand (BOD) Treatment Methods for Palm Oil Mill Effluents (POME). Environmental Technology and Innovation 21:101258-101269. DOI:10.1016/j.eti.2020.101258

Low SS, Bong KX, Mubashir M, Cheng CK, Lam MK, Lim JW, Ho YC, Lee KT, Munawaroh HSH, Show PL (2021). Microalgae Cultivation in Palm Oil Mill Effluent (POME) Treatment and Biofuel Production. Sustainability 13(6):3247-3261. doi:10.3390/su13063247.

Mardiharini M, Azahari DH, Chaidirsyah RM, Obaideen K (2021). Palm oil industry towards Sustainable Development Goals (SDGs) achievements. IOP Conference Series: Earth and Environmental Science 892 012068. DOI:10.1088/1755-1315/892/1/012068

Mbosso C, Degrande A, Villamor GB (2015). Factors affecting the adoption of agricultural innovation: the case of a Ricinodendron heudelotii kernel extraction machine in southern Cameroon. Agroforestry Systems 89:799-811.

Mehraban N, Debela BL, Kalsum U, Qaim M (2022). What about her? Oil palm cultivation and intra-household gender roles. Food Policy 110:102276. https://doi.org/10.1016/j.foodpol.2022.102276.

Murphy DJ, Goggin K, Paterson RRM (2021). Oil palm in the 2020s and beyond: challenges and solutions. CABI Agriculture and Bioscience 39(2):321-344. https://doi.org/10.1186/s43170-021-00058-3.

Myzabella N, Fritschi L, Merdith N, El-Zaemey S, Chih H, Reid A (2019). Occupational Health and Safety in the Palm Oil Industry: A Systematic Review. International Journal of Occupational and Environmental Medicine 10(4):159-173.

Nchanji YK, Nkongho RN, Mala WA (2016). Efficacy of oil palm intercropping by smallholders. Case study in South-West Cameroon. Agroforestry Systems 90:509-519.

Ndeh YN, Asongwe GA, Mbene K, Ngosong C, Fomenky NN, Bame IB, Tening AS (2022). Pursuing development on the Eastern Flank of Mount Cameroon: Implications on its heavy metal status, environmental quality and human security. African Journal of Agricultural Research 18(9):730-741.

Ngone MA, Ajoacha DM, Achiri DT, Tchakount GVT, Ruppel S, Tening AS, Ngosong C (2023). Potential of bio-organic amendment of palm oil mill effluent manure and plant growth-promoting bacteria to enhance the yield and quality of maize grains in Cameroon. Soil Security 11:100090-100102.

Ogunbode TO, Aliku O, Ogungbile PO, Olatubi IV, Adeniyi VA, Akintunde EA (2022). Environmental impact of oil palm processing on some properties of the on-site soil in a growing city in Nigeria. Frontiers Media (10):1-6.

Ohimain E, Izah S, Dorcas A, Cletus I (2014). Small-Scale Palm Oil Processing Business in Nigeria: A Feasibility Study. Greener Journal of Business and Management Studies 4(3):70-82.

Osman AI, Fawzy S, Lichtfouse E, Rooney DW (2023). Planting trees to combat global warming. Environmental Chemistry Letters. https://doi.org/10.1007/s10311-023-01598-y.

Qaim M, Sibhatu KT, Siregar H, Grass I (2020). Environmental, Economic, and Social Consequences of the Oil Palm Boom. Annual Review of Resource Economics 12(1):321-344.

Rao CSM, Rao NB, Swami DV, Ashok P, Roja RG, Rao BB (2023). Management and Processing of Palm Oil (*Elaeis guineensis* Jacq): The Crop for Future. Palm Oil - Current Status and Updates. IntechOpen, DOI: 10.5772/intechopen.108579.

Rival A, Levang P (2014). Palms of controversies: Oil palm and development challenges. Bogor, Indonesia: CIFOR.

Tening AS, Chuyong GB, Asongwe GA, Fonge BA, Lifongo LL, Tandia BK (2013). Nitrate and Ammonium levels of some water bodies and their interaction with some selected properties of soils in Douala metropolis, Cameroon. African Journal of Environmental Science and Technology 7(7):648-656.

Tening AS, Chuyong GB, Asongwe GA, Fonge BA, Mvondo-Ze AD (2014). Heavy metal status in the Rio del Rey mangroves of Cameroon. International Journal of Current Microbiology and Applied Sciences 3(12):701-717.

Ugbogu EA, Okezie E, Dike, ED, Grace O, GO, Ugbogu OC, Ibe C, Iweala, EJ (2021). The Phytochemistry, Ethnobotanical, and Pharmacological Potentials of the Medicinal Plant *Vernonia amygdalina* L. (bitter Leaf). Clinical Complementary Medicine and Pharmacology 1(1):156-179. https://doi.org/10.1016/j.ccmp.

Wicke B, Sikkema R, Dornburg V, Faaij A (2011). Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28(1):193-206.