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THE EFFECTS OF PLANT GROWTH-PROMOTING BACTERIA (PGPR) INOCULATION ON GROWTH, YIELD, AND GRAIN NUTRIENT UPTAKE OF TEFF VARIETIES UNDER FIELD CONDITION

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ABSTRACT: Inoculation of Plant Growth-Promoting Bacteria **(**PGPR) in plant increase rhizosphere fertility and resulted in more efficient uptake of soil nutrients without harming the environment and human health. The present study aimed to examine the effect of either individual or consortium of PGPR inoculation on growth, yield, and grain nutrient uptake of teff varieties. Three potential PGPR strains (*Pseudomonas fluorescens biotype G*, *Enterobacter cloacae ss disolvens*, and *Serratia marcescens ss marcescen*) were used for this study. Field evaluation was carried out in RCBD with three replications and 10 treatments. Highly significant ($P< 0.001$) differences were observed among treatments for Plant height (PH), Panicle length (PL), number of the total spikelet (NTS), shoot dry weight (SDBM), Grain yield (GY), and Straw yield (SY). However, the interaction effect of the two factors (treatment x variety) did not significantly influence agronomic traits and grain nutrient uptake of the teff. The highest PH (133.5 cm), PL (53.2), NTS (30.9), SDBM (18.1 tha^{-1}), SY (10.7 tha^{-1}), and GY (2.7 tha^{-1}) were observed on Dukem variety (Dz-01-974) inoculated with PGPR consortium. The magnitude of increase in grain yield per hectare was 450% over the control. Inoculation of consortium native PGPR showed better performance in promoting plant growth, yield, and grain nutrient uptake of teff varieties compared to the control and could be used as bacterial inoculant to enhance teff production and productivity.

Keywords: Biodiversity, Inoculant, PGPR, Treatment, Teff variety.

INTRODUCTION

Teff [*Eragrostis tef* (Zucc.) Trotter] is an indigenous tropical cereal crop of Ethiopia, and the country is the center of origin and diversity for the crop (Vavilov, 1951). Its grain is used to make injera, a traditional fermented pancake that is one of the major staple foods for about 70 million inhabitants (60% of the entire population) (Reda, 2015). Teff grain has an excellent nutritional profile; with high dietary fiber, high

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levels of minerals, proteins, and carbohydrate contents (Baye, 2014). It contains 11% protein and is an excellent source of essential amino acids (Doris, 2002). It has a low glycemic index and is free from gluten and serves as an alternative food source for people with type 2 diabetes and celiac disease (Baye, 2014).

In Ethiopia, about 6.5 million smallholder farmers grow teff, which is equivalent to 30% of the total area allocated to cereals, followed by maize (23%), sorghum (18%), and wheat (17%) (CSA, 2019). In the 2019/2020 cropping season, the total area covered with teff was 3.1 million hectares with a production of 5.74 million tons. The average productivity of teff in Ethiopia is very low (1.85 t/h) (CSA, 2019) at the smallholder farmer level. The main reason for low teff productivity is nutrient deficiency, susceptibility to lodging (Habtegebrial et al., 2007), low genetic yield potential (Haileselassie et al., 2016) and drought, particularly in the low altitudes areas.

Currently in Ethiopia, teff production and productivity improvement practices were dependent on the heavy application of chemical inputs (such as fertilizers, pesticides, herbicides, etc.) which may have a deleterious effect on soil fertility and nutritional value of farm products. Excessive use of chemical inputs causes environmental pollution, and has major impact on human and animal health through an accumulation of heavy metals and other toxic substances (Tchounwou et al., 2012).

Chemical fertilizers contain acid radicals, like hydrochloride and sulfuric radicals, and hence increase the soil acidity and adversely affect biological diversity within the agricultural land. Some plants can also absorb recalcitrant compounds from the contaminated soil and cause systematic disorders of the consumers (Alori and Babalola, 2018). Therefore, the increasing awareness of environmental pollution and product contamination due to indiscriminate use of chemical inputs has led to the search for new biological technology to improving crop productivity and grain quality without threatening consumer's health. Either individual or consortium PGPR application which can act as biofertilizer and biocontrol agent is one of the alternative mechanisms to use hazardous chemical fertilizer (Tobergte and Curtis,

2013). They are environmental-friendly and renewably provide nutrients to maintain soil health and biology without affecting the environment and human health.

The application of PGPR inoculants constitutes a biological tool to enhance plant nutrition and mitigating the negative impact of conventional chemical inputs. *Pseudomonas*, *Bacillus*, *Azospirillum*, *Azotobacter*, *Enterobacter*, and *Serratia* are the main genera of PGPR that enhance crop productivity and grain quality (Ferreira et al., 2019). Its application can increase plant growth, yield, yield components, and grain nutrient uptake by improving the availability of essential nutrients, growth hormones, production of different lytic enzymes, and secondary metabolites, which inhibit plant pathogens (Gopalakrishnan et al., 2015). According to Zewdie et al. (2000), inoculation of teff varieties with indigenous *Azospirillum* isolates significantly increased grain yield up to 12% over the control. Similarly, Woyessa and Assefa (2011) reported that teff varieties inoculated with native *Pseudomonas fluorescent* and *Bacillus subtilis* showed significant increase in grain yield by 28% and 44% respectively.

In the last two decades, the synergy of two or more PGPR inoculants has been investigated after simultaneous inoculation in the same plant (Mpanga et al., 2019). It has been reported that inoculation with consortia of PGPR has better plant growth promotion as compared to individual inoculations because individual strains supplement each other for their beneficial traits (Singh et al., 2014). According to the report by Wang et al. (2020), the application of PGPR consortia can increase the production and growth of maize and cucumber plants compared to the inoculation of individual bacteria. Moreover, Souza et al. (2015) reported plant inoculation with a consortium of several PGPR strains increases plant growth and yield than individual strains, likely reflecting the various mechanisms used by each strain in the consortium. Despite the various plant growth promotion and biocontrol benefits associated with PGPR listed in the literature, research conducted to examine the effect of native PGPR application on teff to improve growth, yield, and grain nutrient uptake is limited. This study aimed to examine the effect of

individual or consortium native PGPR inoculation on the growth, yield, and yield-related traits as well as grain nutrient uptake of teff varieties under field conditions.

MATERIALS AND METHODS

Description of the study area

The study was conducted at the Debrezeit Agricultural Research Center (DZARC) during the 2019 main cropping season. The research site is geographically located at 08°44'Nand 38°58'E and has an altitude of 1900 m a.s.l. DZARC is located 47 km southeast of Addis Ababa. The mean long-term annual rainfall recorded at the station is 660 mm and the average annual minimum and maximum temperatures are 12°C and 27.4°C, respectively (Wakjira, 2018). The texture of soil in the experimental site was silt loam and composed of 14% clay, 32% sand, 54% silt and its organic carbon content was about 1.26%, which is considered to be low (Roy et al., 2006). According to Olsen et al. (1954) phosphorus (P) rating (m kg^{-1}), the available P content of the experimental site's soil is low (<3). The pH of the soil was 6.96, which is within the suitable range (4 to 8) for teff production and the total nitrogen (N) of the soil (0.12%) is medium; as rated by Havlin et al. (1999).

Materials used in the experiment

Two teff varieties named Magna (Dz-01-196) and Dukem (Dz-01-974) were obtained from DZARC. The teff varieties were selected based on consumer and farmer's preferences for injera making quality and market demand, respectively. Three potential PGPR strains: *Pseudomonas fluorescens biotype G*, *Enterobacter cloacae ss disolvens*, and *Serratia marcescens ss marcescen* identified from teff varieties in a previous study were used as inoculants (Tsegaye et al., 2021). The three PGPR strains were selected from 65 potential PGPR, based on different plant growth-promoting (PGP) traits such as plant growth and yield-enhancing properties, biotic and abiotic stress tolerance property, in addition to seed germination

capability during laboratory and greenhouse evaluation. Detailed information on the bacteria used for the present study is given in Table 1.

Table 1. Potential PGPR strains selected for field experimental trail.

Code of bacterial isolates	PGP properties			Biocontrol properties			Abiotic stress tolerance properties			Seed germination status
	PS	IAA	NF	Pro	HCN	EPS	SL	pH	TP	SVI
Serretia marcescens ss marcescen	+++	+++	+	+++	+	++	5	4,5,7, 9	40	530
Pseudomonas fluorescent biotype G	+++	+++	++	++	+++	+++	10	5,7, 9	30	470
Enterobacter cloacae ss disolvens	++++	++	+++	+++	+	+++	15	5,7	40	540

Note: PS=phosphate solubilization, IAA=indole acetic acid, NF=nitrogen fixation, EPS=exopolysaccharide, SL=salinity, TP=temperature, SVI seed vigor index, +=low, ++=moderate, +++=high and ++++=extreme high. (Source: Tsegaye et al., 2021).

PGPR strains compatibility test

Compatibility among the three selected PGPR strains was tested to formulate bacterial consortia. The method described by Nikam et al. (2007) with slight modifications was used for *in-vitro* bacterial compatibility testing. PGPR cultures streaked on nutrient agar plates in such a way that for every single bacterial culture in the center of the plate, other cultures streaked radiating from the center. The plates were incubated at 30°C for 48 hrs and the zone of inhibition was observed and recorded. Bacterial strains which do not show a zone of inhibition on the growth medium indicate the compatibility of the strains.

Bacterial inoculant preparation

Nutrient broth medium amended with 1% carboxyl methylcellulose (CMC) was prepared and inoculated with the selected potential PGPR strains and shake for 48 hrs in a rotary shaker. After shaking, the density of the culture was measured using a turbidimeter, bacterial cell concentration of 10^6cfu mL^{-1}, and then the cultures used for seed inoculation.

Seed surface sterilization and treatment with bacterial inoculants

Teff seeds were surface sterilized with 70% alcohol for 3 minutes, followed by 1% hypochlorite for 5 minutes, and rinsed 5 times with sterile distilled water. Ten ml of the suspension (10^6 cfu mL^{-1}) of the individual bacterial cells or its consortium were mixed with 2 g of surface-sterilized seed sand used for each plot. The consortium was prepared by mixing an equal amount of suspension of each PGPR cell that has the same $cfumL^{-1}$ (Casanovas et al., 2000). The treated seeds were shade dried for 4 hours and immediately sown in prepared plots.

The field layout and trial management

The land was prepared by tractor plowing and the seedbeds were leveled and compacted before sowing the treated seeds. The experiment was laid out as a randomized complete block design (RCBD) with three replications and 10 treatments. An uninoculated plot was used as a control. A plot size of 2 m x 2 m (4 m^2) with 20 cm row spacing, and a total of 10 rows and 30 plots were used. The spacing between plots and blocks was 0.5 and 1 m, respectively. Inoculated seeds of two varieties were hand drilled at the rate of 5 kg per hectare i.e. 2g/plot. Plots were kept free of weed by hand weeding without using herbicides.

Agronomic data collection, measurement, and grain nutrient analysis

At physiological maturity, plant growth, yield, and yield related data were collected before and after harvesting according to Assefa et al. (2016). Ten plants were selected from the central two rows of each plot to measure plant growth and growth-related parameters. Harvesting was done manually using hand sickle from an area of 1.8 m x 1.8 m (3.24 m^2) to measure grain yield, straw yield, and yield-related parameters. In addition Lodging index (LI) which shows the level of lodging was measured just before the time of harvest by visual observation. It was determined by the angle of inclination of the main stem from the vertical line to the base of the stem measured in 1-5 scale, where 1 (0-15°) indicates no lodging, 2 (15-30°) indicates 25% lodging, 3 (30-45°) indicates 50% lodging, 4 (45-60°) indicates 75% lodging and 5

(60-90°) indicates 100% lodging (Donald, 2004). Data recorded on lodging percentage was subjected to arc sign transformation described for percentage data by Gomez and Gomez (1984).

Nutrient analysis

Teff grain powder (100 g) were prepared from each treatment and sent to laboratories at Debrezeit and Jimma agricultural research centers for macro and micronutrient analysis.

Data analysis

All collected data were analyzed using the R software version 3.6 statistical analysis system following the appropriate procedures of RCBD. A two-way analysis of variance (ANOVA) was conducted to test the significance level of the variables at $p \leq 0.05$. A comparison of the individual treatment means was performed using the least significant difference (LSD).

RESULTS

Effect of PGPR inoculation on teff agronomic traits

Analysis of variance (ANOVA) for agronomic traits showed that traits like plant height, panicle length, number of total spikelet, shoot dry biomass, grain yield, straw yield, and harvest index were significantly affected by PGPR inoculants at 0.1% probability level, while lodging index was significantly affected at 5% probability level. On the other hand, the interaction effect of variety and treatment did not significantly affect the agronomic traits of the two varieties (Table 2).

Table 2. Mean square of treatment, variety, treatment * variety effects on teff agronomic traits.

S.O.V	DF	Growth, yield, and yield-related traits								
		PH	PL	NTS	NFT	SDBM	GY	SY	HI	LI
TM	4	2129.5***	290.2***	120***	24.8ns	11.6***	0.31***	3.4***	0.01**	0.78Ns
VT	1	240.8*	264.0**	41.3^{NS}	3.7^{Ns}	5.4**	0.06^{Ns}	2.5**	0.001	20.8*
TM*VT	4	2.6^{NS}	9.3^{NS}	2.5^{NS}	6.6^{Ns}	0.36^{Ns}	0.03^{NS}	0.23ns	0.001^{NS}	3.1^{Ns}
Error	20	45.2	9.3	10.9	9.5	0.30	0.009	0.25	0.001	4.20

PH=plant height, PL=panicle length, NTS=number of total spikelet, NFT=number of fertile tiler, SDBM=shoot dry weight, GY=grain yield, SY=straw yield, HI=harvest index, LI=lodging and *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability levels, respectively; NS=not significant, S.O.V=source of variation, TM=treatment, VT=variety, DF= degree of freedom.

Effect of PGPR inoculation on teff varieties growth and growth-related traits

Teff varieties inoculated with individual or consortium PGPR showed significantly (P<0.001) increased plant height compared to control (Table 3). The longest PH (133.5 cm) observed on Dukem variety (Dz-01-974) inoculated with the consortium of the PGPR, and the shortest PH (84.1 cm) was observed on uninoculated Magna variety (Dz-01-196). Similarly, the panicle length of both varieties was significantly (P<0.001) increased by inoculation of either individual or consortium PGPR. The longest PL (53.2 cm) observed on Dz-01-974 inoculated with the bacterial consortium and, the shortest PL (31.7 cm) was observed on uninoculated Dz-01-196, which increased panicle length up to 168% over the control. The number of total spikelet of Dz-01-196 was significantly (P<0.01) affected by the inoculation of either individual or consortium PGPR. The smallest NTS (18.4) was observed on uninoculated Dz-01-196 and the highest NTS (30.9) was recorded on Dz-01-974 inoculated with PGPR consortium, which exceeds the number of total spikelet up to 168% over the control. The number of fertile tillers was significantly affected by *Enterobacter cloacae ss dissolvens* inoculation. The maximum NFT (12.3) was observed on Dz-01-974 and, the shortest PL (5.1) was recorded on uninoculated Dz-01-196.

Table 3. PGPR inoculation effects on teff varieties' growth and growth-related traits.

Treatment	Mean teff growth-promoting traits							
	PH		PL		NTS		NFT	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem
Control	84.1[b]	88.8[b]	31.7[b]	33.5[b]	18.4[b]	19.5[b]	5.1[a]	5.7[b]
Serratia marcescens ss marcescens	122.5[a]	128.9[a]	44.3a	50.1[a]	27.9[a]	29.7[a]	9.7[a]	8.6a[b]
Pseudomonas fluorescens biotype G	124.8[a]	129.6[a]	43.6[a]	51.5[a]	26.1[a]	30.7[a]	6.9[a]	7.4[ab]
Enterobacter cloacae ss dissolvens	125.5a	133.1[a]	43.0[a]	50.9[a]	27.7[a]	29.6[a]	8.0[a]	12.3[a]
Bacteria consortium	128.7[a]	133.5[a]	46.7[a]	53.2[a]	28.6[a]	30.9[a]	9.8[a]	10.3[ab]
LSD (5%)	8.35	13.49	5.94	5.11	6.02	6.04	4.24	6.71
P-value	0.001	0.001	0.001	0.001	0.01	0.01	0.23	0.24

PH=plant height, PL=panicle length, NTS =number of total spikelet, NFT=number of fertile tiller and the letters (a, b) indicate significant differences at P≤0.05 according to the LSD test.

Effect of PGPR inoculation on teff yield and yield-related traits

Individual treatment means comparison results showed that the shoot dry biomass, grain yield, and straw yield of both varieties were significantly (P< 0.001) influenced by inoculation of PGPR inoculants either alone or in combination (Table 4). The maximum SDBM (18.1 tha^{-1}) was obtained from Dz-01-974 (Dukem) inoculated with the PGPR consortium, and the minimum SDBM (5.8 t ha^{-1}) was obtained from uninoculated Dz-01-196 (Magna). The consortium inoculation exceeded shoot dry biomass by about 312% over the control. Regarding the grain yield, the maximum GY (2.7 t ha^{-1}) obtained from Dz-01-974 was inoculated with the PGPR consortium, and the minimum GY (0.60 t/ ha^{-1}) was recorded from uninoculated Dz-01-196. The magnitude of increase in grain yield was higher by about 450% over the uninoculated plots. Similarly, the lowest straw yield (3.5 t ha^{-1}) was obtained from uninoculated Dz-01-196, and the highest SY (10.7 t ha^{-1}) was obtained from Dz-01-974 inoculated with the PGPR consortium, which exceeds by 306% over the control plots. The results of the individual treatment mean comparison revealed that the harvest index (HI) of both varieties was significantly (P<0.05) influenced by the application of either individual or consortium PGPR. The minimum HI (16%) was observed on untreated

Dz-01-974, and the maximum HI (27%) was observed on Dz-01-196 inoculated by the PGPR consortium, which increases harvest index up to 169% over the control.

Table 4. Effect of PGPR inoculation on yield, and yield-related traits of tested teff varieties.

Treatment	Mean teff yield and yield-related parameters (tone/ha)									
	SDBM t ha^{-1}		GY t ha^{-1}		SY t ha^{-1}		HI %		LI %	
	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Dukem	Magna	Duke
Control	5.8^{b}	5.9^{b}	0.60^{b}	0.61^{b}	3.5^{b}	3.7^{b}	17^{c}	16^{b}	20^{a}	21^{a}
Serratia marcescens ss marcescens	14.0^{a}	16.5^{a}	1.9^{a}	2.3^{a}	7.9^{a}	9.6^{a}	25a	24^{a}	25^{a}	27^{a}
Pseudomonas fluorescens biotype G	13.8^{a}	16.4^{a}	1.7^{b}	2.4^{a}	7.4^{a}	9.4^{a}	22^{b}	25^{a}	26^{a}	24^{a}
Enterobacter cloacae ss dissolvens	13.7^{a}	17.2^{a}	1.6^{b}	2.6^{a}	7.6^{a}	9.9^{a}	20^{b}	26^{a}	24^{a}	27^{a}
Bacteria consortium	13.8^{a}	18.1^{a}	2.0^{a}	2.7^{a}	7.7^{a}	10.7^{a}	27^{a}	26^{a}	25^{a}	24^{a}
LSD (5%)	1.02	0.20	0.20	0.15	0.20	0.88	0.08	0.04	2.63	2.57
p-value	0.001	0.001	0.003	0.001	0.04	0.001	0.07	0.01	0.55	0.62

SDBM=shoot dry biomass, GY=grain yield, SY=straw yield, HI=harvest index, LI=lodging index and different letters indicate significant differences at P≤0.05 according to the LSD test.

Effects of PGPR inoculation on teff grain nutrient uptake

The result of ANOVA indicated that a significant difference (P≤0.01) was observed on teff varieties on grain nitrogen (N), phosphorus (P), and calcium (Ca) uptake by treatment (Table 5). Grain magnesium (Mg) and iron (Fe) uptake were significantly affected by a variety at a 5% probability level.

Table 5. ANOVA for treatment and variety effects on teff grain nutrient uptake.

S.O.V	D.F	N %	P %	S	K %	Mg %	Ca %	Zn %	Fe %
TM	4	1.76^{**}	1.88^{**}	0.45^{*}	0.006^{Ns}	0.001^{Ns}	0.06^{**}	0.00001Ns	0.0002Ns
VT	1	0.01^{Ns}	0.06^{Ns}	0.001^{Ns}	0.003^{Ns}	0.01*	0.001^{Ns}	0.00002Ns	0.01^{*}
Error	4	0.003	0.05	0.03	0.005	0.0004	0.001	0.00001	0.0003

N=nitrogen, P=phosphorus, S=Sulphur, K=potassium, Mg=magnesium, Ca=calcium, Zn=zinc, Fe=iron and *, **, ***: statistically significant at P≤0.05, P≤0.01, and P≤0.001 probability level, respectively; Ns: not significant, S.O.V=source of variation, D.F= degree of freedom, TM=treatment, VT=variety.

Effects of PGPR inoculation on teff grain macro and micronutrient uptake

Individual treatment means comparison showed that teff grain nitrogen (N%), phosphorus (P%), Sulphur (S%), and calcium (Ca%) uptake were significantly affected by individual or consortium PGPR inoculation (Table 6).

Table 6. Individual treatment means of PGPR inoculation on teff grain nutrient content improvement.

Treatment	N %	P %	S %	K %	Mg %	Ca	Zn%	Fe
Control	1.42 ^{b}	0.67^{c}	0.38^{c}	0.44^{a}	0.09^{a}	0.06^{b}	0.00^{a}	0.04^{a}
Serratia marcescens ss marcescens	1.78 ^{a}	2.44^{b}	1.28^{ab}	0.36^{a}	0.12^{a}	0.07^{b}	0.05^{a}	0.05^{a}
Pseudomonas fluorescens biotype G	1.76^{a}	2.18^{b}	1.41^{ab}	0.42^{a}	0.14^{a}	0.08^{a}	0.00^{a}	0.04^{a}
Enterobacter cloacae ss dissolvens	1.71^{a}	2.07^{b}	1.06b	0.31^{a}	0.13^{a}	0.09^{a}	0.05^{a}	0.04^{a}
Bacteria consortium	1.85 ^{a}	3.35^{a}	1.61a	0.44^{a}	0.14^{a}	0.19^{a}	0.05^{a}	0.05^{a}
LSD (0.05)	0.17	0.60	0.40	0.17	0.09	0.09	0.006	0.09

N=nitrogen, P=phosphorus, S=Sulphur, K=potassium, Mg=magnesium, Ca=calcium, Zn=zinc, Fe=iron, different letters indicate significant differences at P≤0.05 according to the LSD test.

The maximum teff grain N (1.85%), P (3.35%), S (1.61%), and Ca (0.19%) uptake was observed on teff variety inoculated with PGPR consortium, and the smallest grain N (1.42 %), P (0.67%), S (0.38%), and Ca (0.06%) uptake was recorded on uninoculated control. Either individual or consortium PGPR inoculation did not significantly affect uptake of potassium (K), Zinc (Zn), magnesium (Mg), and iron (Fe) although differences were recorded between the inoculated and uninoculated treatments.

DISCUSSION

Results in the present study showed that the compatibility of the three PGP strains and their inoculation either alone or in combination significantly increased growth, yield, yield-related parameters, and grain nutrient uptake of the two teff varieties over the control. Similarly, Kumar et al. (2017) reported that inoculation of PGPR either alone or in various combinations significantly ($P \leq 0.05$) increased the growth and yield of wheat compared to untreated controls.

The study indicated that the Dukem (Dz-01-974) variety responded better for all agronomic traits than Magna (Dz-01-196) variety to PGPR treatment either alone or in combination. Each teff variety responded differently to different bacterial inoculation indicating bacterial physiologic, metabolic, and root colonization ability differences, as well as the existence of some degree of specificity that might affect growth, yield, and other parameters of the varieties. Zewdie et al. (2000) reported that higher grain yield responses were observed for the teff variety Dz-01-096 compared to Dz-01-354 by the inoculation of the Azospirilium isolates.

Inoculation of the PGPR consortium on the two teff varieties showed better performance on plant growth, yield, and grain nutrient uptake than the individual inoculants. Grain and biomass yield were significantly ($P<0.001$) increased by the inoculation of PGPR consortium. Meena et al. (2016) reported that the application of PGPR as a consortium of compatible strains has been more effective than their single application in the practical field. Similarly, Souza et al. (2015) reported that plant inoculation with a consortium of several bacterial strains might be an alternative to inoculation with individual strains, likely reflecting the various mechanisms employed by each strain within the consortium. PGPR consortium has a synergetic effect to mobilize essential nutrients, synthesizing different hormones, and suitably beating the challenges like biotic and abiotic stress conditions as that they had adapted to different environmental conditions.

Plant height, panicle length, and the number of total spikelet are the most important traits affecting plant growth (Idota et al., 2015). In our study, on the tested teff varieties plant height, panicle length, and the number of total spikelet were significantly affected by inoculation of PGPR. Woyessa and Assefa (2011) reported inoculation of *Pseudomonas fluorescent* and *Bacillus subtilis* significantly increased growth of teff variety. Longer plant height and panicles allow more spikelets that contain better number of grains.

In this study, shoot dry biomasses of both varieties were significantly increased by inoculation of either individual or consortium PGPR inoculants. The maximum shoot dry biomass was obtained from Dz-01-

974 inoculated by the PGPR consortium. Similarly, Kausar and Shahzad (2006) reported that inoculation of maize with PGPR strains caused a significant increase in shoot dry matter. This could be due to an increase in the availability of essential soil nutrients and other substances through the synergistic effects of the PGPR consortium that can boost the shoot dry biomass of the teff varieties. The lowest shoot biomass was observed on the plots where no inoculants were applied. This indicated that the experimental soils had limitations in releasing essential nutrients in adequate amounts to support teff plant growth and development without additional inputs.

There were significant differences in teff grain yield by the inoculation of either individual or consortium PGPR. The highest grain yield was observed on Dz-01-974 inoculated with PGPR consortium, which exceeds 450% over the control. Sarma et al. (2009) reported that a mixture of two *Fluorescent pseudomonas* strains increased the yield of *Vigna mungo* by 300% in comparison to the control. These could be for the reason that a consortium of PGPR increases the availability of the nutrients that are essential to enhance the yield of the plant by using various PGP mechanisms like phosphate solubilization, nitrogen fixation, production of the different secondary metabolites as well as improving plants' tolerance to biotic and abiotic stress factors.

The straw yield of cereal crops is an important agronomic parameter that is sensitive to soil nutrient availability or the nutrient applied from external sources (Tamene et al., 2017). In the present study, the application of consortium PGPR inoculants significantly ($P<0.001$) affects straw yield. Zafar-ul-Hye et al., (2020) reported multi-strain inoculation with PGPR are more effective than single-strain inoculation to improve wheat (*Triticum aestivum*) straw yield. This could be due to the interaction effect of the bacterial consortium that improves the supply of unavailable nutrients and different hormones to the teff varieties.

Harvest index indicates the balance between the productive parts of the plant and the reserves. It indicates the presence of good partitioning of biological yield. In the present study, the individual treatments mean result revealed that the harvest index of the teff varieties significantly increased by inoculation of

consortium PGPR inoculants over control. These results showed that the PGPR consortium could improve the supply of essential nutrients to the plant and increase the harvest index.

No significant difference was observed on lodging index between the two varieties of teff upon inoculation by PGPR either alone or in a consortium although differences occurred between inoculated and uninoculated treatments. PGPR inoculant might improve teff varieties stem strengthen through regulating the supply of nutrient and increase root growth to prevent lodging problems.

Inoculation of either individual or consortium PGPR inoculants significantly improved grain N, P, S and Ca uptake of the two teff varieties over the control. Mantelin and Touraine (2004) reported that plants inoculated with PGPR significantly increase uptake of nutrient elements like Ca, K, Fe, Cu, Mn, and Zn through proton pump ATPase. Moreover, Karlidag et al. (2007) reported that inoculation of Bacillus and micro bacterium inoculants improved uptake of mineral elements by apple plants. Furthermore, Kumar et al. (2017) reported that co-inoculation of *Enterobacter* with *S. marcescens* and *M. arborescens* improved grain N and P uptake of wheat variety in field experiment.

In general, the present study confirmed that the PGPR consortium application was capable of enhancing the growth, yield, yield-related parameters, and grain nutrient uptake of the two teff varieties. However, the bacterial consortium displayed a marked difference in their effect on several features of growth and productivity of Dukem (Dz-01-974) teff variety. The variation perhaps originated by PGPR consortium are differences in exerting PGP mechanisms and synergy to supplying essential nutrients to the teff varieties.

CONCLUSION AND RECOMMENDATION

This study concluded that the utilization of native PGPR either alone or consortium as bio inoculants could reduce the global dependence on hazardous chemical inputs, which threaten the environment, human health, as well as biodiversity. Furthermore, sustained teff production and productivity without affecting grain yield and quality of the grain nutrients is an important agricultural practice to meet

consumer's demand at the regional and national level. Further evaluation and demonstration could be conducted by inoculation of either individual or consortium PGPR inoculants on different crop varieties under different environmental conditions to explain the role of native PGPR as bacterial inoculants.

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KNOWLEDGE, ATTITUDE AND PRACTICE ON WATER HYACINTH (*EICHHORNIA CRASSIPES*) AMONG COMMUNITIES ADJACENT TO RIFT VALLEY LAKES, ETHIOPIA

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ABSTRACT: Water hyacinth (*Eichhornia crassipes*) remains as one of the top notorious invasive species threatening biodiversity, socio-economy, and health in tropics and subtropics of the globe. Public awareness, views and practices are weighty to prevent and manage its invasion. In this survey the knowledge, attitude, and practice of communities adjacent to Rift Valley Lakes were assessed through cross-sectional study design. Data were collected using semi structured questionnaires. The mean knowledge and attitude scores were significantly different by gender, education, and occupation ($\alpha = 5\%$, $P \leq 0.05$). High level (> 50%) of knowledge and attitude were scored by 68.75% and 85% of respondents, respectively. More than half of the respondents scored a low practice level. Those who scored high practice (> 50%) represented 38.70% of the total respondents. Majority of respondents understood the adverse impacts, infestation factors, and some biological natures of water hyacinth. All respondents felt discomfort with the presence of the weed, and they had willingness to participate in cleanup attempts. Overall, this survey showed that most of the adjacent communities had promising baseline knowledge of the weed and positive attitude to prevent its future invasion, but less practice to control its spread. The knowledge and attitude of the local communities has the potential to be translated into good water hyacinth management practices. Thus, the major actors particularly, the Ethiopian Biodiversity Institute, Regional Environment, Forest and Climate Change Authority, Federal and Regional water resource and agriculture related bureaus should act to translate communities' knowledge and attitude into practices.

Keywords: Attitude, Invasive plants, Knowledge, Practice, Rift valley lakes, Water hyacinth.

INTRODUCTION

Water hyacinth [*Eichhornia crassipes* (Mart.) Solms] remains one of the top notorious aquatic weeds in the world posing severe damage on biodiversity, ecosystem functionality, socio-economy, and human health. It originates from the rain forests of the Amazon River, South America and has been introduced to

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other parts of the world in the 19th century (Sharma et al., 2016). To date, its infestation has been reported in over 50 countries of tropical, subtropical and warm temperate regions of the five continents: Southeast Asia, the Southeastern United States, Central and Western Africa, and Central America (Rakotoarisoa et al., 2015; Sharma et al., 2016). In Africa, since the time of its introduction in late of 1800s, it has aggressively colonized vital freshwater bodies and wetlands: particularly in South Africa (Ilo et al., 2020), Zimbabwe (Chapungu et al., 2018), Ghana (Honlah et al., 2019), Nigeria (Ayanda et al., 2020), Kenya (Otieno, 2014), and Ethiopia (Enyew et al., 2020).The weed was officially reported in Ethiopia about 60 years ago in Koka reservoir and Awash River (Stroud, 1994). Thenceforth, it remains problematic taking over wetlands and freshwater bodies of the country: Tana, Abaya, Koka, Koka Dam, Ziway, Ellen, Baro-Akobo River Basin (Sobate, Baro, Gillo and Pibor rivers), and Elltoke (Taye et al., 2009; Mengist and Moges, 2019; Enyew et al., 2020; Yigermal et al., 2020). The infestation is becoming the worst, threatening the country's aquatic ecosystems services and biodiversity including native mammals, birds, fishes, algae and aquatic plants (Mengist and Moges, 2019; Enyew et al., 2020; Hussien et al., 2020).

Humans are a key dimension of biological invasions, acting as drivers for their introduction, experiencing the consequences of their uncontrolled expansion and deciding on the management of those species (Shackleton et al., 2019; Vaz et al., 2020). Social awareness and perceptions are keys for achieving successful management actions, including their control or eradication (Shackleton et al., 2019; Vaz et al., 2020). Certainly, communities' better knowledge and attitude play crucial roles to mitigate the adverse impacts and manage future invasion (Luna et al., 2019). Foremost, understanding public awareness and beliefs becomes a priority action while developing action plans for the strategic management of invasive species (Shackleton and Shackleton 2016; Waliczek et al., 2017). Knowledge, attitude, and practice (KAP) survey represents information on what is known (knowledge), believed (attitude), and done (practiced) in a target population (Andrade et al., 2020). It has become a popular approach to establish quantitative and repeatable measurements of public awareness and actions in the context of a topic of

interest (Wittenberg and Cock, 2001; Zahedi et al., 2014). KAP survey provides social baseline information on the general knowledge, attitude and practice (Ford-Thompson, 2012; Caceres-Escobar et al., 2019). The lack of baseline information on public perception affects resource allocation, planning, program implementation, public engagement, and future invasion prevention (Andrade et al., 2020).

Several impact assessments and empirical studies have been reported, and many recurrent attempts have been made to control the infestation of water hyacinth in Ethiopia. The attempts lacked proper knowledge deliveries and communications with the local communities. Prior survey to identify public baseline knowledge, myths, attitude, beliefs, and behaviors in relation to water hyacinth is absent. The management practices were not strategically guided based on KAP analysis. These could be a reason to the failure of previous water hyacinth control efforts in Ethiopia. On the other hand, water hyacinth management can sometimes face challenges often due to perceived socio-political risks, misconceptions in the local communities, and unexpected technical difficulties (Wang et al., 2019). Thus, to halt the adverse impacts of water hyacinth, it is imperative that we advance not only with eradication protocols and strategies, but also with being conscious of communities' awareness, and with the techniques to engage with local communities when eradication plans are undertaken. This survey aimed to evaluate the knowledge, attitude, and practice of local communities adjacent to Rift Valley lakes (Ziway, Ellen, and Qoqa) in Oromia Region, Ethiopia.

METHODS

Description of the study area

This survey was conducted in four districts of Oromia Region: Adami Tullu (7°52′N38°42′E), Bora (8.30°N 38.95°E), Lume (8°20'00.0"N 36°49'00.0"E), and Dodota (8° 14' 60.00" N 39° 19' 60.00" E). The districts were selected from three zones of Oromia Region: East Shewa, Arsi, and West Arsi. Three lakes namely: Koka (altitude 1584 m a.s.l., water body area 177 Km^2), Ellen (altitude 1700 m a.s.l., water body

area 28 km^2, mean depth 2.5 m), and Ziway (altitude 1636 m a.s.l., water body area 440 Km^2, mean depth 2.5 m), which are found in the Rift Valley of Ethiopia, were selected for the survey (Figure 1).

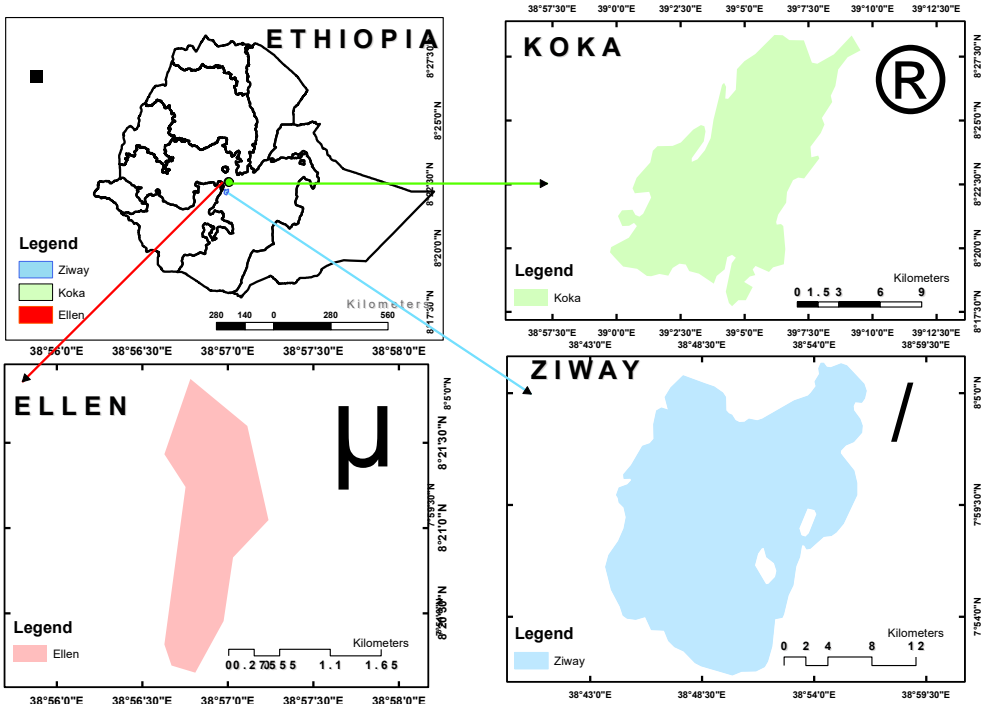

Figure 1. Map of Koka, Ellen and Ziway lakes.

Lake Ziway is one of the largest freshwater bodies found in the Rift Valley. It is located at about 160 Km South of Addis Ababa (7052' to 808'N latitude and 7052' to 38056'E longitude). The lake is situated at an altitude of 1636 m above sea level with a surface area of 434 Km^2 and mean of depth 2.5 m (Gebremedhin and Belliethathan, 2019). Its maximum depth is 9 m with average depth of 2.5 m; the volume is approximately 1.1 billion m^3 (Tamiru, 2019). After the late 1980s, it showed a slight reduction, which is reported to be a result of uncontrolled water abstractions for small-scale irrigation schemes in the upper reaches of the catchments (Tamiru, 2019). Lake Ziway provides 7-8 million cubic meters of water per year for domestic, livestock, and for the municipality of Ziway Town. It also serves as a source of water

for open and closed farm irrigation and contributes a huge fish market supply in the country. A large number of local people including women and children depend on the lake for their livelihoods. Along with its economic and livelihood values, the watershed of the lake supports the varieties of biodiversity and unique ecological services (Gebremedhin and Belliethathan, 2019; Tamiru, 2019).

Lake Koka is actually a reservoir created by the Koka Dam, constructed in the late 1950s and opened in 1960 for hydropower, flood control, and irrigation (Kloos and Legesse, 2010). It is located in the Ethiopian Rift Valley (08°23'22" N - 39°05'15" E) at an altitude of 1590 m a.s.l., about 90 km Southeast of Addis Ababa. It has 255 Km^2 area coverage with a maximum and mean depth of 14 m and 9 m, respectively; it has 1191 tons of fishery potential per year (Gashaw and Wolff, 2015; Hussien et al., 2020). The climate is characterized by a four-months dry season (November to February) and an eight-months rainy season (March to October). The total annual rainfall varies from 600-800 mm and the mean annual temperature ranges from 20-26°C. The pH of the water ranges from 8-9 and conductivity from 200-393 µS/cm (Gashaw and Wolff, 2015). The local communities of the lake have utilized the resources as a source of livelihood income. Parts of the landscapes are mainly agricultural lands populated by smallholders. The water of the lake is used for irrigation, bathing, recreation, and drinking water for domestic use and wildlife. The fisheries and tourism of the lake supply vital fish production and income for the local people in the area.

Lake Ellen is located at 08°23' N longitude, 38°59' E latitude and at an altitude of 1700 m a.s.l, eight kilometer west of Alem Tena town in Dugda Bora District of Oromia region (Samuel and Nestanet, 2014). It has 28 Km^2 water body area coverage and 2.5 meters mean of depth (Gebregiorgis, 2017), and it is currently expanding to Rift Valley lakes. The lake provides important resources for the livelihood of the local communities such as drinking water, fishing, irrigation, transportation and recreation. In addition to being a key strategic resource for sustaining local people's livelihood, and promoting economic development; it maintains the varieties of both aquatic and terrestrial biodiversity in the area.

Household selection and data collection

The study zones and districts were selected purposely based on the information obtained from the Environment Forest and Wildlife Protection and Development Authority of Oromia Region considering the degree of infestation of the lakes. The districts were chosen by the Zonal Environment Forest and Wildlife Protection and Development Authority based on the socio-economic values of the lakes and dependency of the adjacent communities on the lakes. Consulting the Wildlife Protection and Development Authority of the districts, 131 fishers and farmers who depended on the lakes for fishing and/or farming were listed, and then 67 males and 13 females were randomly sampled from the list using lottery method. Then, the selected respondents were recruited after obtaining their consent to participate in the study.

The data were collected using semi structured questionnaires. In the process, respondents were asked to explain their views on factors promoting water hyacinth introduction, growth and spread, adverse impact on biodiversity, socio-economy, and health; the beliefs and misconceptions in the population to prevent, control and manage water hyacinth, the adverse impacts on the lakes and aquatic biodiversity; and the practical experiences they had to prevent, control and manage, and the control methods they were using to handle water hyacinth proliferation.

Data analysis

Data were summarized using descriptive statistics and presented by percentages, frequency distribution, tables, and graphs. In order to check for all possible differences among groups, analysis of variance (ANOVA) was used. Comparisons between groups were made using Student's t-test for continuous variables. Data were analyzed using SPSS Statistics for Windows, version 21 (IBM Corp., N.Y., USA), and graphs were built using Excel Microsoft Office 2016.

RESULTS

Demography

The average age of respondents was 41.78 ± 14.23 with minimum19 and maximum 78 years. Ninety-five percent were engaged in either fishing, or farming or both. Five percent were running a small business such as giving transportation services on the lakes and vending fish products. In data analysis, this segment was added to respondents who were engaged in both fishing and farming. Table 1 presents the socio demographic characteristics of respondents.

Table 1. Respondents' demographics characteristics by their district.

Demography		Districts								Total	
		Adami Tullu		Bora		Dodota		Lume			
		N	%	N	%	N	%	N	%	N	%
Gender	Male	12	100	21	63.64	12	100	22	95.65	67	83.75
	Female	0	0	12	36.36	0	0	1	4.35	13	16.25
Age	< 25	0	0	6	18.20	0	0	1	4.35	7	8.75
	25-44	7	58.30	16	48.50	8	66.66	9	39.13	40	50.00
	45-64	5	41.70	10	30.30	2	16.67	10	43.48	27	33.75
	>64	0	0	1	3.00	2	16.67	3	13.04	6	7.50
Education	Illiterate	3	25.00	18	54.55	2	16.67	8	34.78	31	38.75
	Primary	6	50.00	14	42.42	6	50.00	10	43.48	36	45.00
	Secondary+	3	25.00	1	3.03	4	33.33	5	21.74	13	16.25
Occupation	Fishing	12	100	7	21.21	3	25.00	6	26.09	28	35.00
	Farming	0	0	12	36.36	5	41.67	9	39.13	26	32.50
	Fishing & Farming	0	0	14	42.42	4	33.33	8	34.78	26	32.50

Access to information

Seventy-four percent of the respondents claimed that they did not hear any information about water hyacinth from any print or electronic media before. Twenty six percent were informed about the weed either by Regional Media outlets, or Ziway Fisheries Resources Research Center (ZFRRC) or Zonal Environment, Forest and Climate Change Authority (EFCCA) office (Figure 2).

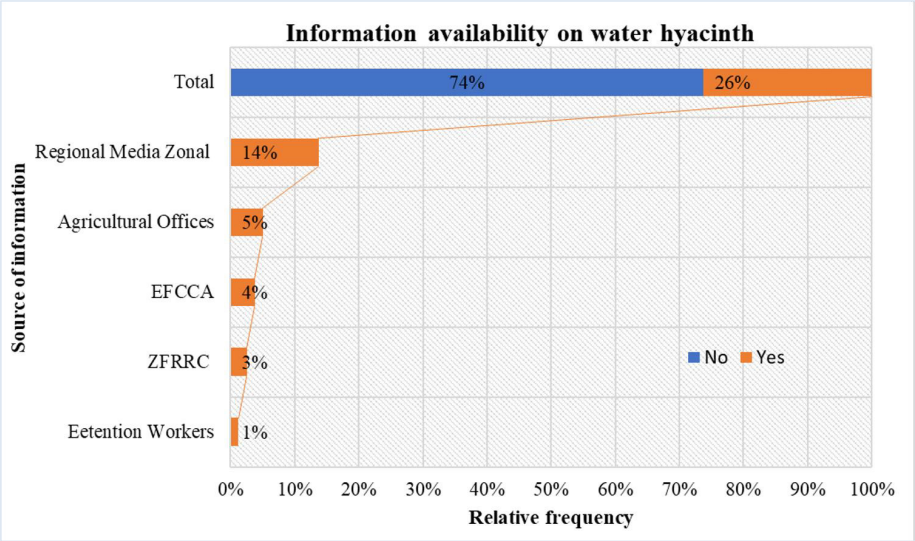

Figure 2. Information sources for respondents on water hyacinth. EFCCA- Environment, Forest and Climate Change Authority, ZFRRC- Ziway Fisheries Resources Research Center.

Date of introduction

The time that the respondents noticed water hyacinth on the lakes ranged between 1962 and 2002 and it shows significant correlation with the age of the respondents (α = 5%, p = 0.00). Figure 3 presents the relationships between the age of respondents and the year they noticed water hyacinth on the three lakes.

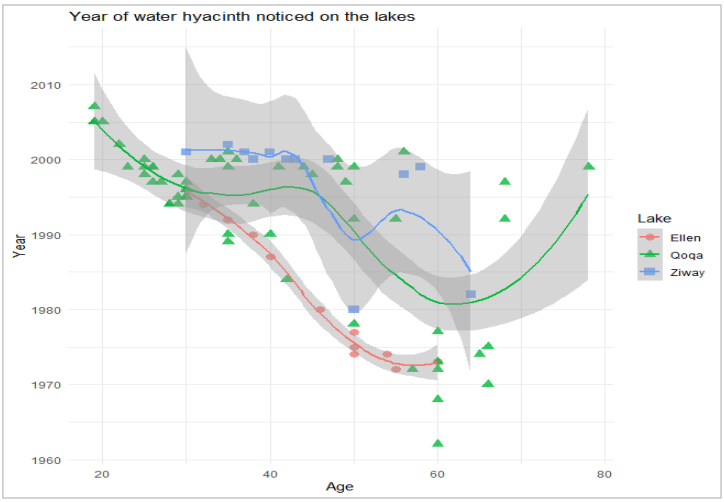

Figure 3. Relationships between age of respondents and the year they noticed water hyacinth on the lakes.

Methods of introduction

Half of the respondents (50%) thought Awash River brought water hyacinths from infested areas and dispersed on the lakes. Others (31%) listed flood, wind, and intentional importation by humans for mulch (Figure 4) while 15 respondents (19%) claimed that they were not sure how water hyacinth was introduced on the lakes.

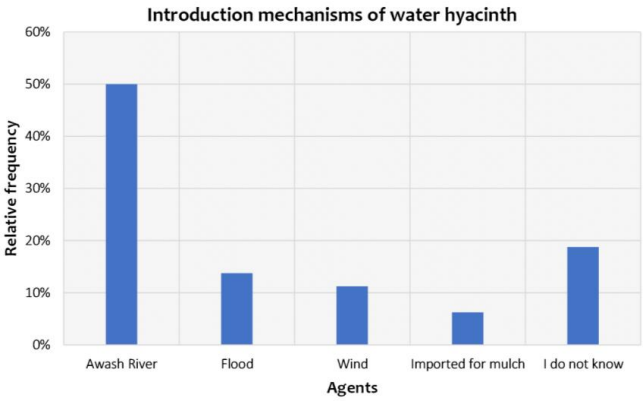

Figure4. Views of respondents on how water hyacinth was introduced into the lakes.

Factors promoting growth and spread

Respondents listed seven major factors that promoted the growth and rapid spread of water hyacinthon the lakes (Figure 5). Flood was the most frequently mentioned factor, followed bythe biological nature of water hyacinth (particularly its rapid reproduction rate) and wind (transporting from infested areas to uninfested areas). Of the total respondents, 30 (37.5%) claimed that agricultural and urban wastes had promoted the rapid infestation and growth of water hyacinth in the past years.

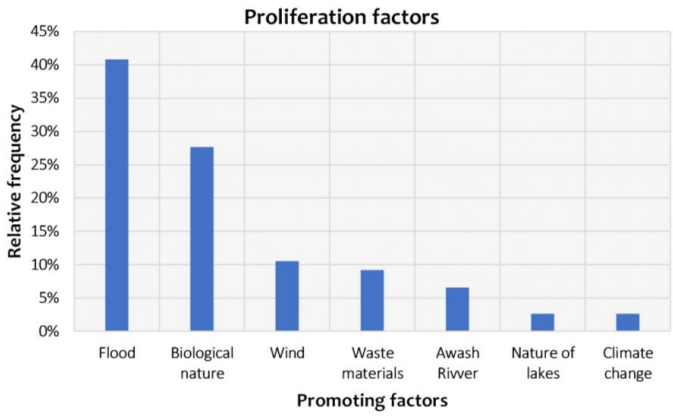

Figure 5. Views of respondents on factors promoting the growth and spread of water hyacinth on the lakes.

Knowledge

The average knowledge score of respondents was 65.64 ± 14.65 and it ranged from 23.08to 92.31.Comparison of the knowledge score of males and females indicated the presence of significant difference (independent samples t-test; t (78) = 3.53, p = 0.001, 95% CI (6.37 – 22.89)). The mean knowledge score of respondents was significantly different by education level (One-Way ANOVA; F(2) = 4.022, P = 0.022). The knowledge score of fishers, farmers, and those who engaged in both fishing and farming significantly varied within groups (One-Way ANOVA; F(2) = 5.772, P = 0.005). Table 2 presents the detailed comparison of knowledge scores by socio demographic characteristics.

Of the survey population, 55 (68.75%) scored high level of knowledge (above 50%). The mean high-level knowledge score was 64.20 ± 10.28. The minimum (53.85) and the maximum (92.31) high-level knowledge scores represented 22.50% and 2.50% of the total sample population, respectively. The mean high-level knowledge scores of fishers, farmers, and respondents who were engaged in fishing and farming were 66.67, 58.97, and 66.80, respectively; and there were statistically significant differences among them. The mean high-level knowledge score of respondents who had information access and who had no information access from any printed or electronic media were 67.52 and 62.58, respectively.

Table 2. Multiple comparisons of knowledge score of respondents by demographic characteristics.

Demography	Category	Mean	Comparison			P – value
			Category-1	Category-2	P – value	
Gender	Male	59.01	-	-	-	0.001
	Female	44.38	-	-	-	
Age‡	< 25	52.75	<25	25-44	0.56	0.82
				45-64	0.37	
	25-44	56.35		>64	0.77	
	45-64	58.41	25-44	45-64	0.58	
				>64	0.85	
	>64	55.13	45-64	>64	0.63	
Education	Illiterate	51.37	Illiterate	Primary	.036	0.022
	Primary	58.76		Secondary +	.012	
	Secondary +	63.31	Primary	Secondary +	.322	
Occupation	Fishing	58.58	Fishing	Farming	.029	0.005
	Farming	50.37		Fishing & Farming	.281	
	Fishing & Farming	62.88	Farming	Fishing & Farming	.002	
Work experience	<11	53.52	<11	11-25	.023	0.056
	11-25	62.90		>25	.179	
	>25	59.14	11-25	>25	.452	
Access to information	Yes	63.74	-	-	-	0.009
	No	54.11	-	-	-	

‡ The age group is based on United Nations (1982)

Attitude

The attitude score of respondents was varied with 63.19 mean, 55.56 range, and 13.76 standard deviation. The minimum attitude score was 33.33, and this accounted for 7.50% of the total sample population. The maximum attitude score of the respondents was 88.89 representing 5% of the total sample population. The

attitude scores of illiterates, 58.07; primary school, 67.28, and secondary school, 64.10, were significantly different at α = 5% One-way ANOVA test (p = 0.021). The attitude score of fishers, farmers, and those who engaged in both fishing and farming significantly varied within a group α = 5% One-way ANOVA test (p = 0.004). Table 3 shows the comparison of respondents' attitude score by demographic characteristics.

Of the survey population, 85% scored a high level of attitude (above 50%). The mean of high-level attitude score was 67.48 ± 9.66. The minimum high-level attitude score (55.56) accounted for 23.75% of the total sample population. The maximum high-level attitude score (88.89) represented 5% of the total sample population. There was a significant mean difference between male (68.97) and female (58.89) high-level attitude scores (independent samples t-test; t(66) = 3.26, p = 0.002, 95% CI (3.90 – 16.25)). The mean high-level attitude score of respondents who had access to information and who had no access to information on water hyacinth were 68.89 and 66.90 respectively, with non-significant difference.

Table 3. Multiple comparisons of attitude score of respondents by demographic characteristics.

Demography	Category	Mean	Comparison			P – value
			Category-1	Category-2	P – value	
Gender	Male	64.84	-	-	-	0.014
	Female	54.70	-	-	-	
Age	< 25	60.32	<25	25-44	0.53	0.82
				45-64	0.56	
	25-44	63.89		>64	0.89	
	45-64	63.79	25-44	45-64	0.98	
				>64	0.45	
	>64	59.26	45-64	>64	0.47	
Education	Illiterate	58.07	Illiterate	Primary	.006	0.021
	Primary	67.28		Secondary +	.172	
	Secondary +	64.10	Primary	Secondary +	.461	
Occupation	Fishing	64.53	Fishing	Farming	.040	0.004
	Farming	57.35		Fishing & Farming	.178	
	Fishing & Farming	69.57	Farming	Fishing & Farming	.001	
Work experience	<11	61.47	<11	11-25	.097	0.25
	11-25	67.97		>25	.664	
	>25	63.19	11-25	>25	.319	
Access to information	Yes	67.73	-	-	-	0.079
	No	61.58	-	-	-	

Practice

The mean practice score of the survey population was 50 ± 17.34. The minimum was 33.33, and this accounted for 61.30% of the total sample population. The maximum practice score was 66.67 representing 38.70% of the total sample population. Of the survey population, only 38.70% of respondents scored a high level of practice (above 50%). Table 4 shows the comparison of respondents' practice score by demographic characteristics.

Table 4. Multiple comparisons of practice score of respondents by demographic characteristics.

Demography	Category	Mean	Comparison			P – value
			Category-1	Category-2	P – value	
Gender	Male	51.49	-	-	-	0.080
	Female	42.31	-	-	-	
Age	< 25	42.86	< 25	25-44	0.58	0.49
				45-64	0.35	
	25-44	46.67		>64	0.67	
	45-64	49.38	25-44	45-64	0.51	
				>64	0.29	
	>64	38.89	45-64	>64	0.16	
Education	Illiterate	49.19	Illiterate	Primary	.728	0.941
	Primary	50.69		Secondary +	.890	
	Secondary +	50.00	Primary	Secondary +	.903	
Occupation	Fishing	54.81	Fishing	Farming	.165	0.216
	Farming	48.39		Fishing & Farming	.106	
	Fishing & Farming	46.74	Farming	Fishing & Farming	.729	
Work experience	<11	48.40	<11	11-25	.361	0.607
	11-25	52.94		>25	.534	
	>25	51.56	11-25	>25	.821	
Access to information	Yes	50.42	-	-	-	0.717
	No	48.81	-	-	-	

DISCUSSION

The results in this survey showed that the local communities, farmers and fishers, in particular those adjacent to the Rift Valley lakes Ziway, Ellen, and Qoqa had basic understanding of water hyacinth's adverse impacts, infestation factors, and some of its biological natures. The results also demonstrated that

the local communities felt discomfort with the presence of water hyacinth on the lakes, and they had willingness to participate in any future cleanup attempts.

Awash River, flood, wind, and importation for mulch were listed by respondents as agents that introduced water hyacinth on the lakes. The response to our questionnaires showed that significant respondents thought Awash River brought water hyacinth from Aba Samuel Dam in the 20th century and then disseminated on local lakes via flood and wind. Equivalent evidence was also reported that water hyacinth first appeared in Koka reservoir and disseminated to other parts of the country (Stroud, 1994; Gaikwad and Gavande, 2017; Dersseh et al., 2019). A report by Stroud (1994) highlighted that water hyacinth was introduced to Koka dam and Awash River about half a century ago, and then it was transported to other parts of the country. As per the respondents, the rapid growth and spread have been extensively promoted by factors such as flood, biological nature of the weed, wind, waste materials, Awash River, and climate change. Notably, 30 (37.5%) of the respondents contended that agricultural and urban effluents were massively responsible for promoting the spread of the weed on the lakes. These observations were also reported in other studies which highlighted eutrophication as the main cause of water hyacinth proliferation on Aba Samuel Dam (Taye et al., 2009; Ingwani et al., 2010; Ebro et al., 2017); and Akaki River was the major cause for the Aba Samuel Dam's eutrophication. Since the time of its introduction, as argued by respondents, water hyacinth infestation has been increasing every year posing damaging impacts on socio-economic activities and livelihoods of the local communities (Enyew et al., 2020; Yigermal et al., 2020). Overall, the extent of communities' knowledge and attitude could help to develop comprehensive prevention, control, and management mechanisms to prevail over the infestation problems.

Apart from the promising communities' knowledge and attitude to water hyacinth, socio demographic factors determined the knowledge and attitude scores among individuals. For instance, the availability of information on water hyacinth from any print or electronic media, the types of socio-economic activities that depended on the lakes and educational background had sensible linkage with the knowledge and

attitude scores of the respondents. The differences in social awareness and views on water hyacinth have a potential to complicate management actions or can lead to inefficient control efforts (Shackleton et al., 2019). Thus, considering the effects of social structures on public knowledge and information attainments, the gap should be addressed either through training or media delivery systems (Peng et al., 2019). Fishers had better awareness about the socio-economic, environmental, and health impacts of water hyacinth than farmers who withdraw water from the lakes for irrigation. This variation could be related to the time they spend on the lakes for fishing and being more familiar with the weed on their way. It was especially noted that respondents had a clear knowledge constraint to fairly list possible methods to control water hyacinth. For example, none of the respondents mentioned water hyacinth control methods other than manual approach (uprooting), and nobody was conscious about the economic potential of the weed through biomass utilization (Wang et al., 2019), or using it in small-scale cottage industries (e.g., producing goods for domestic uses) which does not require huge investment (Fawad and Jamal, 2019). This finding is useful as it can be used for community-based learning of water hyacinth control methods to address the limitations. In addition, communities' responsiveness should be scaled up through training to be successful in prevention, control, and management measures (Lindemann-Matthies, 2016).

The practice score of respondents was much lower than their knowledge and attitude scores. The majority of the respondents (61.30%), achieved below average practice score (33.33). Perhaps, the communities were not clearly aware of what kind of measures should be taken to prevent or control water hyacinth from their local areas. For instance, from the total respondent who had information on water hyacinth from any print or electronic media, 71% achieved the highest practice score, which represented 46.88% of the total high practice scorers. Their knowledge (66.16) and attitude (69.63) scores were higher than the mean score of the remaining respondents 54.44 and 61.71, respectively. Taking these together, it is clear that educating the communities about the weed not only equip them with basic knowledge, but also guide them to take appropriate actions against the damaging impacts of water hyacinth on biodiversity and

ecosystem. A similar survey conducted in Kenya reported that lack of access to information on water hyacinth control mechanisms was associated with the reason why Kenyans were not swiftly taking measures to control water hyacinth whenever it invades water bodies (Mironga, 2014). Equally, respondents' low practice score might be attributed to lack of appropriate organization to mobilize and engage them for action, lack of equipment to clean it up, expecting governmental intervention, and believing that the infestation is beyond their control. These views were frequently reflected and noted throughout the data collection session. Therefore, addressing the gaps, engaging and mobilizing the communities could help to curb water hyacinth spread (Alison and Kirsty, 2007; Ingwani, et al., 2010; Vaz et al., 2020).

To conclude, water hyacinth has remained problematic colonizing the wetlands and freshwater bodies of Ethiopia. Public awareness and perceptions are weighty to prevent and manage the invasion of water hyacinth. The purpose of this survey was to evaluate the knowledge, attitude, and practice of the local communities adjacent to Rift Valley lakes namely Ziway, Ellen, and Qoqa. The local communities (farmers and fishers in particular) had promising knowledge and attitudes on water hyacinth. They had basic understanding about the adverse impacts and its invasion catalysts, felt discomfort with the weed's presence on the lakes, and had willingness to participate in future cleanup attempts. However, socio demographic factors moderately determined communities' knowledge and attitude scores, and the practice scores to prevent and control water hyacinth infestation was very low. This survey is the first KAP study on water hyacinth in Ethiopia, and it can provide baseline information for further studies.

The knowledge and attitude of the local communities has the potential to be translated into better water hyacinth management practices. Therefore, the major actors in biodiversity and ecosystem services, agriculture, and water resources management related activities particularly the Ethiopian Biodiversity Institute, Federal Environment, Forest and Climate Change Commission, Federal and Regional Water,

Irrigation and Energy Offices and Agricultural Bureaus should act accordingly to halt the problems caused by water hyacinth.

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ECONOMIC VALUATION OF CONSERVING AFRICAN ELEPHANT (*LOXODONTA AFRICANA*) IN CHEBERA-CHURCHURA NATIONAL PARK, ETHIOPIA

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ABSTRACT: The African elephant (*Loxodonta africana*) is one of the world's endangered species of large mammals. One of the main reasons for wild animals decline in Ethiopia is habitat destruction due to various human needs, insufficient budget allocation for managing protected areas, and other factors. In addition, incorporating economic valuation for conserving wild animal species from a total economic valuation perspective has been little studied. The present study was conducted to determine willingness to pay (WTP) using contingent valuation for the conservation of African elephant using a sample of rural residents (n = 183) living adjacent to Chebera-Churchura National Park (CCNP). Logit model was used to analyze variables that determine respondent's willingness to pay. The result showed that most of the households (83%) were willing to support the conservation of elephants in CCNP. Variables such as crop damage by elephant, awareness of respondents about the importance of elephant for present and future generations, the income of respondents, and location of residents from the park were the major determinant of respondents' willingness to pay. Residents were willing to pay up to 2.78 million birr which is equivalent to about 95 thousand USD (average exchange rate in the 2019 year; 1$ = 29.2 birr) annually for the conservation of African elephant in CCNP within four years. The result showed that commitment of local communities in support of the government in the conservation of African elephant is very promising and economic valuation in wild animal conservation has to be considered.

Keywords: African elephant, Chebera-Churchura National Park, Economic valuation, Willingness to pay.

INTRODUCTION

The African elephant (*Loxodonta africana*) belongs to the order Proboscidea and the family Elephantidae. It is the largest land mammal surviving on Earth. Elephants are a keystone species that their interactions with other species generate effects (Carignan and Villard, 2002). They are also umbrella or flagship species (Selier et al., 2016). Being an umbrella species, elephants require a vast home range and intact

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areas to maintain their population. Hence, conserving elephants means protecting many other species that share habitat with elephants. Similarly, elephants as a flagship species they can easily attract public support for conservation. This opportunity may help many other species which share the elephant's habitat or are vulnerable to the same threats to be conserved.

African elephant occurs in 37 countries in sub-Saharan Africa including Ethiopia (Selieret al., 2016). In Ethiopia, it was widely distributed throughout the country except in the most northern highlands and Denakil desert (Yaldenet al., 1986). However, currently, they are mainly found in few localities, including Babile Elephant Sanctuary, Chebra-Churchura, Omo, Mago, Kafta-shiraro, and Gambella National Parks. About 90% of elephant population has been lost since the 1980s. As a result, only an estimated 1500 to 2000 elephants are found in Ethiopia (Sintayehu, 2016). The major causes of a rapid decline are poaching for the illegal ivory trade, habitat fragmentation caused by human population expansion, and rapid land conversion (Meseret, 2006; Selieret al., 2016). These threats are also a case in Chebera-Churchura National Park (CCNP). The expansion of agricultural activities in this park resulted in intense human-elephant conflict. Elephants frequently come to agricultural lands, raid crops, destruct crop stores, and harass people in almost all parts of the CCNP (Meseret, 2006; Gizachew, 2016).

Scientists argue that economic criteria and local community involvement have to be part of the design and implementation of conservation policies (MEA, 2005; TEEB, 2009). Similarly, international agreements such as the Convention on Biological Diversity recognize the importance of understanding the economic value of biodiversity for conservation and policymaking (Martin-Lopez et al., 2008). This is because environmental economics can inform conservation biologists and policymakers about why species are endangered, the opportunity costs of conservation activities, and the economic incentives for conservation (Shogren et al., 1999).

Failure to involve local communities contribution to wildlife conservation is one of the causes of species decline all over the world. Conversely, considering appropriate economic values to species enables to halt

the decline of wildlife species and reverse the situation (Plan, 1999; Land and Water Australia, 2005; Martin-Lopez et al., 2008). Thus, economic valuation needs to be appropriately interpreted and embedded in sound wildlife management processes. Valuation supports the use of cost-efficient compensation mechanisms in human-wildlife conflicting areas. When the costs of communities living around the protected areas cannot be met by alternative sources of income, a well-designed compensation program can fill the gap (TEEB, 2009).

People value wild animal species for different reasons and benefit from their conservation in different ways. The total benefits of conservation are generally partitioned between those arising from use or non-use values which together comprise a species total economic value (White et al., 1997; Pascual et al., 2010) (Figure 1). The use-values include direct, indirect and option-use while the non-use values are bequest, altruist and existence values (Pascual et al., 2010).

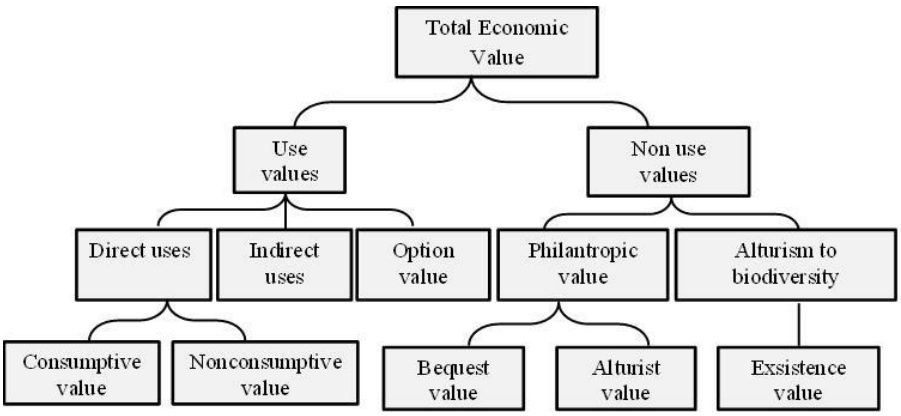

Figure 1. The economic value of biodiversity (De Groot et al., 2002).

Direct use values of wild animals are outputs that are directly consumable, such as food and recreations, while indirect-use values include activities such as observation and photography. Individuals may also benefit from indirect uses activities such as enjoyment gained by reading about or viewing photographs and motions pictures of species (Kotchen and Reiling, 1998).

The bequest value for a resource is the value of knowing the fact that future generations will also have access to the benefits from species. Altruist value refers to the fact that other people of the present generation have access to the benefits provided by species and the existence value refers to the value/satisfaction of knowing that it continues to exist. The direct and to less extent the indirect value may have a well-defined monetary component.

The option value and non-use value are typically far more difficult to define for the existing market since non-use values are related to moral, religious or aesthetic properties, for which markets usually do not exist (Pascual et al., 2010). However, these derived values for non-market benefits may be controversial, thus more efforts should be made to assess and incorporate them into the decision-making process (White et al., 1997).

Measuring non-market benefits using public willingness to pay is, therefore, an appropriate measurement and has been used in previous studies to give meaningful estimates of the anthropocentric benefits of conserving rare and endangered species (Loomis and White, 1996). Contingent valuation method using a willingness to pay is applied to determine direct use, non-use or passive use (existence and bequest values) and option use-values, but not indirect use values (Plan, 1999). Thus, the contingent valuation method differs from all other important economic valuation methods, which can only be used to determine one type of use-value (Plan, 1999). Therefore, this study aims to investigate the relative total economic values of the African elephant by evaluating public willingness to pay towards its conservation in Chebera-Churchura National Park.

MATERIALS AND METHODS

Description of the study area

Chebera-Churchura National Park is situated along the southwestern part of Ethiopia (Figure 2). It is located within Dawro zone and Konta special district of Southern Nation, Nationalities and Peoples Regional State, about 300 and 580 km southwest of Awassa and Addis Ababa, respectively. It was

established in 2005 and covers an area of 1215 km^2. The altitude ranges between 700 to 2450 m a.s.l (Gizachew, 2016). It lies between the coordinates 36°27'00"- 36°57'14"E longitude and 6°56'05"-7°08'02"N latitude. CCNP is bordered by Konta special district to the north, Omo River to the south, Dawro zone to the east and southeast, and Agare high mountains and Omo River to the west (Gizachew, 2016). The livelihoods of the community living around the park depend on traditional agriculture.

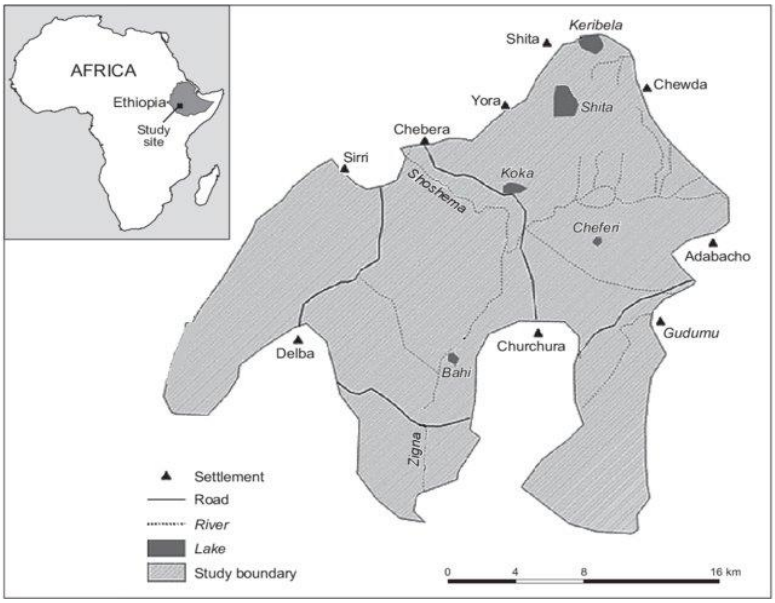

Figure 2. Map of CCNP and surrounding Kebeles (Aberham et al., 2017).

Methods

Sample size and data collection methods

Sampling and data collection was made in March 2019using households living in four rural Kebeles adjacent to CCNP as the target population (Figure 2) (Table 1). The four kebeles were selected purposely due to existing high human-wildlife conflict and their proximity to the park. The sample size was determined by using a rule-of-thumb N ≥50 + 8 m for the multiple correlations (Green, 1991). Where N =

minimum sample size and m = number of predictors. A total of 183 samples/individual households were selected randomly using proportional allocation methods from 2,133 target population.

Table 1. Rural kebeles and their respective house hold's population size.

Selected Kebeles	Population	Samples
Gudumu	953	82
Chawuda	477	41
Chebera	420	36
Siri	283	24
Total	2133	183

Data were collected through household interviews using a semi-structured questionnaire to elicit respondents' willingness to pay for the conservation of elephant in the park. The questionnaire consisted of perception of residents to elephant conservation, willingness to pay, demographic, and socioeconomic characteristics of residents (Rodgers, 2001; Bandara and Tisdell, 2003).

Elicitation method

Before the actual interview, the respondents were brainstormed about the decline of African elephant in particular and wildlife in general in CCNP due to anthropogenic threats. Rapid human population growth creates great pressure on elephant survival through habitat loss (settlement, farmland expansion, overgrazing and others), human-wildlife conflict, and poaching. In addition, weak institutional and park administration capacities (budget, manpower etc.), poor coordination of concerned bodies, and other factors greatly contributed to the rapid decline of elephant in the park. Therefore, socially acceptable strategies for an appropriate level of co-existence between farmers and elephants are needed; mainly such co-existence may be supported with compensation to farmers whose property lost to tolerate elephants' conflict (Bandara and Tisdell, 2003).

Hypothetical Strategy

The respondents were informed of the importance of adopting a new strategy to ensure the survival of African elephant for the long-term and to address related issues. The new strategy was a hypothetical strategy (scenario) that protects the African elephant and benefits the local community (Loomis and White, 1996; Zewdu and Yemesrach, 2003). The new strategy implementation measures for the conservation of African elephant were explained to the respondents. The implemented measures include the provision of extra elephant conservation measures, improve tourist destination facilities such as elephant observation sites by organizing communities and promote communities to benefit from the income generated by these activities, establish compensation funding for farmers whose property or crop has been damaged by elephant, rewarding farmers who arrest poachers or inform to scouts, and others. As explained to the respondents, the new conservation strategy was based on active participation of interested households that have close contact with the elephant habitat along with the government.

The respondents were also informed about the need to finance and establish a 'Trust fund' to support the proposed African elephant conservation strategy (Land and Water Australia, 2005). The possible benefits that communities would gain such as employment and increase the income generated from tourism, compensation for crop or property damage by elephant, and others were explained to respondents.

Then, the respondents were subjected to the contingent market valuation questions as follows: "Are you willing to pay 5, 10 or 20 birr per year for the next four years (starting from January 1, 2020), towards the establishment of a trust fund by increasing your land use tax for the implementation of the proposed program to conserve African elephants in the park”?

Payment vehicle

The respondents were requested to choose payment options during focus group discussion among the given alternatives: payment with rural land use fee, annual donation form, and other forms of payment. Respondents prefer to pay their contribution along with their annual rural land use tax. Respondents’

capacity to the willingness to pay was determined by analyzing the pilot survey results. The capacity of respondents' willingness to pay a given bid (offer to pay a particular amount of money for something) of 5, 10, and 20 birr per year were offered to choose (Han et al., 2010; Andualem et al., 2017). The dichotomous choice format was used to assess respondents' willingness to pay (WTP) and a logistic regression model was used to determine the significant factor affecting the WTP dichotomous format (Hanemann et al., 1991; Kanninen and Khawaja, 1995; Han et al., 2010).

$WTPi = \alpha + \beta Xi + vi$ Where,

WTPi is the willingness to pay of individual i

α is some constant

Xi is a vector of demographic variables, and

vi is a normally distributed random term with a mean of zero and a variance = $\sigma 2$ (i.e. $Vi \sim N(0, \sigma 2)$).

Let y represent a dichotomous variable that equals 1 if the respondent was willing to pay, and 0 otherwise. The model of the probability of WTP, P (yi= 1), was represented as:

In [yi=1/1-p (yi=1)]

$= ß_o + ß_1(Age) + ß_2 (Sex) + ß_3 (Income) + ß_4 (Distance) + ß_5 (Cropraid) + ß_6 (Attitude)$

Data analysis

Demographic and socioeconomic data were analyzed using descriptive statistics in the form of frequency, percentage, median, and mean. The logistic regression model was used to determine the association of dependent and independent variables. All statistics were analyzed using SPSS 20 software. P-value less than 0.05 at 95% confidence level was used to test significance value.

RESULTS

Respondents' socioeconomic and demographic characteristics

One-hundred eighty-three household heads with 58 (31.7%) females and 125 (68.3%) males, were interviewed from four different kebeles adjacent to CCNP. The majority of the respondents were between

31-45 years of age followed by 17-30 years, which accounts for 48.6% and 32.2%, respectively. Respondents with these age range were expected to have more experience with elephant and wildlife living in the park to respond to the questions reasonably. Seventy-nine of respondents (43.2%) were illiterate while 60 respondents (32.8%) have attended primary education. The majority of respondents 148 (80.9%) were living within 0.1-5 km away from the park border (Table 2). Nearly half of the respondents complained of crop damage caused by elephants. Most of the respondents 143 (78.1%) knew the importance of conserving elephant and other wildlife in the park while the remaining 21.9% did not have such attitudes.

Table 2. Socioeconomic and demographic status of respondents.

Variables	Category	Frequency	Percentage
Age	17-30	59	32.2
	31-45	89	48.6
	46-60	30	16.4
	>60	5	2.7
Sex	F	58	31.7
	M	125	68.3
Education background	Illiterate	79	43.2
	Informal	31	16.9
	Primary	60	32.8
	Secondary	12	6.6
	College	1	0.5
Distance (Km)	0.1 - 5	148	80.9
	5.1- 10	0	0
	10.1- 15	2	1.1
	15.1- 20	33	18
Status of crop raid	Yes	90	49.2
	No	93	50.8
Attitude for the importance of elephant	Yes	143	78.1
	No	40	21.9

Estimation of willingness to pay

One-hundred fifty-one (82.5 %) of the respondents were willing to pay for the conservation of African elephant while the remaining 32 (17.5%) refused to pay anything at all (Table 3). Of those who were willing to pay, 41% were willing to pay the lower amount (five birr) followed by 10 birr which accounts

for 34% of respondents. The mean and the median of the willingness to pay were 10.5 birr and 10 birr, respectively. The median is lower than the mean, which means the distribution is negatively skewed. On average, each respondent was willing to pay 1,580 birr per year. Extrapolating this result into the target population, an aggregate (N = 1760) of nearly 2.78 million birr which is equivalent to about 95 thousand USD (the average exchange rate in the 2019 year; 1$ = 29.2 birr) was estimated annually willing to contribute to the conservation of African elephant in CCNP by excluding the proportion of population who refused the WTP.

Table 3. The frequency of Bid for WTP.

Bid value (Birr)	Frequency	Percent
0	32	17.5
5	62	33.9
10	51	27.9
20	38	20.7
Total	183	100

Note: Zero indicates respondents refused to pay for the conservation of elephant.

Respondents' reason for supporting or refusing WTP

Among respondents, 39.1% were willing to pay mainly because they believed that the elephants to be conserved. While the remaining 31.8% and 29.1% of respondents hoped to be benefited from a proposed project that would be implemented, and both to conserve and benefit, respectively. However, more than 50% of the respondents who refused to support elephant conservation were due to their poor economic status. The reasons why respondents support or refuse the conservation of elephant are given in tables 4 and 5.

Table 4. Reasons why respondents support the conservation of elephant (WTP).

Variables	Frequency	Percent
Elephant has to be conserved	59	39.1
To benefit from the conservation project	48	31.8
To conserve and benefit from the conservation program	44	29.1
Total	151	100

Table 5. Reasons why respondents refuse the conservation of elephant.

Variable	Frequency	Percent
Poverty	18	56.2
Elephant is not important	3	9.4
Conservation is government's responsibility	8	25
Other reasons	3	9.4
Total	32	100

Factors that influence WTP

The maximum likelihood estimates for the logistic regression model is presented in Table 6.

Table 6. Results of logistic regression analysis.

Variables	B	S.E.	Wald	df	Sig.	Exp (B)
Age	.008	.034	.049	1	.824	1.008
Sex	1.646	.793	4.307	1	.038*	5.184
Income	.008	.002	18.963	1	.000*	1.008
Distance (km)	-.159	.051	9.865	1	.002*	.853
Crop raid	3.644	1.011	12.990	1	.000*	38.242
Attitude	3.003	.871	11.891	1	.001*	20.143
Constant	-4.889	1.817	7.237	1	.007	.008
Model χ^2 value			102.226		.000	
-2Log likelihood			64.279			
Model percentage of correct prediction			92.9			

Respondents' sex, household income, crop raid and awareness of households about the elephant's importance to present and future generations (attitude) had a significant positive effect on respondents' WTP at 5% significant level. The average monthly income of the respondent was estimated to be 454 birr.

The residents' location from the park (distance in km) had a significant negative effect on respondents' WTP. Respondents are living on average about 4 km away from the park boundary. The age of respondents had no significant effect on respondents' WTP. Generally, the Logit model had nearly 93% prediction ability.

DISCUSSION

In this study, most of the respondents were willing to pay for the conservation of African elephant. Higher positive responses recorded on WTP may be attributed to regular community awareness creation activities conducted for wildlife conservation by scouts and district environmental experts. The result is slightly lower than 88.7% reported by Bandard and Tisdell (2003) on Siri Lanka elephant but higher than what has been reported by Han et al., (2010) and Andualem et al. (2017) which were 73% and 69%, respectively. A slightly lower positive response in the current study compared to that of Siri Lanka is attributed to the educational status of respondents. In the present study, respondents were from rural communities with high illiteracy status (43%) while in Siri Lanka they were urban people with minimum illiteracy status.

In this study, respondents agreed to pay about 2.78 million birr annually (equivalent to about 95 thousand USD). This is a great contribution to the conservation of African elephant in CCNP for the next four years. Such a commitment from local communities in support of the government in the conservation of African elephant is very promising. However, the finding revealed the incidence of crop damage by elephant significantly affecting the respondent' WTP. Keeping other variables constant, one unit increase in crop damage caused 38 times more increase in the respondents' WTP for the conservation of African elephant. Crop damage caused by elephant increased communitys' negative attitudes towards elephant existence in their vicinity. However, the response of respondents was contrary to this idea, may be because respondents believed that implementation of the newly proposed activity may minimize the negative impact of crop damage through compensation mechanisms and other income-generating activities.

The second major factor with a significant positive effect on respondents' willingness to support the conservation of elephant was awareness of respondents about the importance of elephant and other wildlife resources for the future generation. One unit change in attitudes of respondents resulted in 20 times more increase in respondents' WTP for the conservation of African elephant. The current positive result is consistent with other similar studies conducted in Ethiopia and elsewhere (Bandara and Tisdell, 2003; Han et al., 2010; Andualemet al., 2017). The reason why respondents' attitude has a positive impact towards WTP in the present study could be associated with continuous formal and informal awareness creation programs of communities by district biodiversity experts and scouts that enable respondents to develop a positive attitude towards elephant and be willing to pay for their conservation.

The third dummy variable that significantly affected respondents' WTP was the sex of respondents. Males were five times more likely willing to pay than females. This could be attributed to that males have more exposure to environmental concerns and other training activities than females. A similar result was reported by Andualem et al. (2017).

The other variable which significantly affected respondents' WTP was households' income. This result agrees with the study by Andualem et al. (2017) and Tadesse (2014). For every one-unit increase in households' income, respondents' WTP doubled. This is because as household income increases, communities will have some money left from goods, clothing, and other expenditures to contribute to elephant conservation.

The last variable that significantly affected the respondents' WTP was residents' distance from the park. For every one kilometer away from the park, the respondent's WTP decreased by 0.85 times. The reason why respondents living near the park were interested to pay more may be attributed to the anticipated compensation from the conservation program to crop damage caused by elephant. However, the age of respondents did not affect respondents WTP. Similar results were reported by Zewdu and Yemesrach

(2003) and Han et al. (2010). This may show that local communities living around the park have a similar understanding of wildlife conservation.

CONCLUSION AND RECOMMENDATIONS

Currently, proliferating anthropogenic and natural factors threatened the survival of African elephant in Ethiopia. A well-coordinated engagement of all stakeholders and exploiting all possible conservation options is crucial for the effective conservation of African elephant. One of the options which have been neglected by policy-makers is the lack of incorporating the economic valuation for wildlife conservation including African elephant. Therefore, the finding of this study indicated that there is good economic support from the local communities for the conservation of African elephant in CCNP. As a result, incorporating economic valuation programs that mobilizing resources and proper implemention could alleviate the financial problem facing CCNP conservation activities. It is also important to scale up these findings to other National Parks for effective management of wildlife in the country.

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MEDICINAL PLANTS OF GAMO PEOPLE IN BONKE WOREDA OF GAMO ZONE, SOUTHERN ETHIOPIA

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ABSTRACT: A study on medicinal plants of Gamo people was conducted in Bonke Woreda (District) of Gamo Zone, Southern Ethiopia, with the general objective of investigating the traditional medicinal practice, identifying and documenting medicinal plant species and associated traditional knowledge and assessing threats to medicinal plant resources and their customary use. Relevant information was gathered from 70 informants. The informants, except the healers, were selected following a random sampling technique. The relevant data were collected using semi-structured interviews, field observations, guided field walks and group discussions. Seventy seven plant species belonging to 69 genera and 38 families and used for treating 66 ailments were identified. Of these, 55 medicinal plant species were reported to have been used for curing human ailments, 10 species for curing livestock ailments and 12 species for treating both human and livestock ailments. Most of the medicinal species were collected from home gardens (48.75%) followed by wild habitats (38.75%). Leaves and roots are the most frequently utilized medicinal plant parts. The widely used remedy administration is orally followed by dermal application. Among the medicinal plants used in the woreda, *Ruta chalepensis* is the most preferred medicinal plant to treat stomach diseases, whereas *Datura stramonium* is the most effective medicinal plant to cure diarrhea. *Dodonaea angustifolia* ranks first in terms of its various uses. Medicinal plant species and the associated knowledge are under serious threat. This calls for appropriate and timely interventions for ensuring the conservation of the plant resources and the continuation of the traditional medicinal practices on which the local healthcare system heavily relies.

Keywords: Bonke, Gamo, Medicinal plants, Traditional knowledge.

INTRODUCTION

Traditional medicine (TM), in its inclusive form, encompasses health practices, approaches, knowledge and beliefs incorporating plant, animal and mineral-based medicines, spiritual therapies, manual

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techniques and exercises, applied singularly or in combination to treat, diagnose, prevent illnesses and maintain wellbeing (WHO, 2002). TM is the most ancient method of curing diseases (Abdullahi, 2011) and a widely used healthcare system with major economic importance. It has been asserted that plants are the very first and the only true medicine ever used (Soladoye et al., 2011) and plants that possess therapeutic properties or exert beneficial pharmacological effects on the human or animal body are generally designated as medicinal plants (Khan et al., 2013).

The plant-based healthcare system has persisted for millennia and remains intact among local communities as the main treatment option for different illnesses for such reasons as shortage of pharmaceutical products, inaccessibility of health service centers, unaffordable modern medicines, emergence and re-emergence of certain diseases, as well as the appearance of drug-resistant microbes and/or helminths (Ketema et al., 2013).

Like elsewhere in the developing world, TM has played and continued to play a significant role in treating health problems in both livestock and humans in Ethiopia. Up to 80% of the country's population uses traditional medicine due to the cultural acceptability of healers and other factors (Ketema et al., 2013). In the practice, MPs remain the most important and sometimes the only source of therapeutics (Tesfaye et al., 2009). The significant role of medicinal plants in the primary healthcare system of Ethiopia has been supported by various studies as established by a systematic review on the subject by Endashaw (2007). While 1000 identified MP species are reported in the Ethiopian Flora volumes (Edwards, 2001), many others are not yet identified and about 300 of these species are frequently mentioned in many sources (Edwards, 2001; Gidey, 2010).

It is generally recognized that there exists a rich traditional medicinal knowledge in Ethiopia (Endashaw, 2007; Balcha, 2014; Gadisa et al., 2018) which is as equally important as the biological resource base. However, this aspect of TM is not studied well and hence not fully identified and documented (Haile and

Delenasaw, 2007). This important category of knowledge, which has mainly been passed orally from generation to generation has, therefore, been subject to erosion for long (Behailu, 2010).

Although traditional medicine remains to be the major available healthcare service for the majority of the population in the developing world (WHO, 2002), it is often considered as a practice that serves no purpose by modern health professionals, and there still is a tendency to attribute its continued existence only to lack of access to modern healthcare service. Such negative attitudes stem from misgivings about its biomedical values and also a host of other factors (Getachew et al., 2004). As Abbink (2002) indicated, it is common to come across with obvious rejection of indigenous medicine by healthcare service providers, even in remote localities; and such unfair treatments have already resulted in dismay by local communities who rely on the healthcare system. Depletion or local extinction of medicinal plant species originate from a host of factors like deforestation, overexploitation, overgrazing, habitat degradation and loss, agricultural land expansion (Mesfin and Mekonnen, 2001; Endashaw, 2007), and unsustainable extraction or harvesting of medicinal plant resources (Balcha, 2014). The serious erosion of traditional medicine-related knowledge (Gadisa et al., 2018) had further worsened the harm made to the valuable traditional practice.

The Gamo people like other rural communities of Ethiopia, have been using traditional medicines and still heavily rely on plant-based remedies. However, the traditional medicinal system is confronted with threats of neglect and erosion as elsewhere in the country. This necessitates a timely investigation of the local medicinal practices to have an insight into the practice and also document its different aspects. Therefore, this study was conducted with the general objectives to investigate the traditional medicinal practice, identify and document medicinal plant species and associated traditional knowledge and assess threats to medicinal plant resources and their customary use.

METHODS

Description of the study area

Bonke (5° 41' 58" to 6° 12' 46" N and 37° 04' 11" to 37° 25' 07" E), is one of the Woredas in Gamo zone, Southern Nations, Nationalities and Peoples Regional State of Ethiopia (Figure 1). Its main town, Geresse, is located 559 km southwest of Addis Ababa and at 54 km distance from Arba Minch town, the zonal capital. The relief of the woreda is characterized by an undulating plain of extensive lowlands, hills and high plateau with an altitude ranging between 900-3200 m a.s.l. Different ethnic groups live in the Woreda with the Gamo people constituting the indigenous and dominant community. *Gamotho* is the local language of the community. Local community members are engaged in mixed farming with barley, wheat, pulses, the Ethiopian indigenous crop Enset (*Ensete ventricosum*) and Taro (*Colocasia esculenta*) being the major tuber crops.

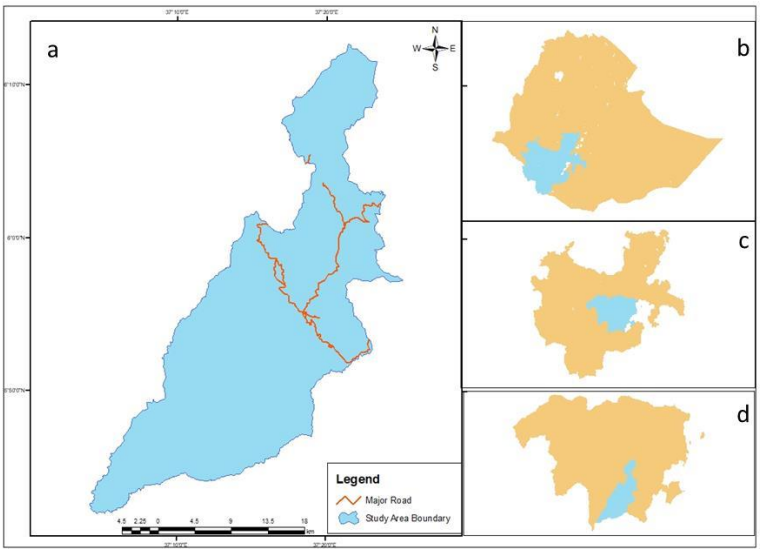

Figure 1. Map of the study area: (a) Bonke woreda, (b) Map of Ethiopia showing SNNPR regional state, (c) Gamo zone in SNNPR regional state, (d) Bonke woreda in Gamo zone.

Data collection and analysis

A reconnaissance survey was conducted at first to select the study kebeles (farmers' villages) in the woreda. Accordingly, seven kebeles were identified from where information on traditional medicinal practice, plant habitats, local healers and plant resources were gathered. Before starting the actual data collection task, members of the local administration and participants of the study were informed about the objective of the research in order to secure their consent. Semi-structured interviews that we reorganized in the form of a checklist helped to address key issues. Additionally, group discussions that focused on common diseases of the studied villages, medicinal plants used to treat ailments, preference to medicinal plants, parts of medicinal plants used and mode of preparation, trend of use and threats to medicinal plants were held with informants of different groups. Seventy individuals (53 men and 17 women) between the ages of 19 and 86 were selected from the seven kebeles as a source of information. Of these, 16 were identified as key informants based on recommendations of local community members, agricultural development agents and members of the local administration.Information on plant species used for treating diseases, plant parts harvested, methods of remedy preparation, aspects of administration and dosage were among the major issues the key informants were requested to provide information on.

Sample specimens of plants cited for their medicinal use were collected, numbered, pressed and dried for identification. Plant species identification was done in the field and at Arba Minch University using the Flora of Ethiopia and Eritrea Volumes 2-7 (Edwards, 1989; Edwards et al., 1995; Hedberg and Edwards, 1995; Edwards et al., 1997; Edwards et al., 2000; Hedberg et al., 2003; Hedberg et al., 2004; Hedberg et al., 2006). This was followed by identification by an expert for some species. The identified species were stored at Arba Minch University's herbarium.

Data analysis

Informant Consensus Factor (ICF) was calculated for each category to identify the agreements of the informants on the reported cures for the group of ailments using the equation:

ICF = Nur – Nt / (Nur – 1), where:

ICF = Informant Consensus Factor,

Nur = number of use citations in each category from informants and

Nt = number of species used

To assess informants' preference of medicinal plants used for treating human diseases, a simple preference ranking and a paired comparison tests were conducted. Furthermore, a direct matrix ranking method was employed to determine the rank of woody medicinal plants of various uses.

RESULTS AND DISCUSSION

Medicinal plant resources of the study area

Seventy-seven plant species belonging to 68 genera and 38 families were documented as having a medicinal value in the study area. Among these, 55 plant species were used for treating only human ailments (Appendix 1), 10 species for treating only livestock ailments (Appendix 2) whereas the rest 12 plant species are mentioned to have been used for treating both human and livestock ailments (Appendix 3). Concerning species diversity of the recorded plant families, Asteraceae and Lamiaceae stood first, each contributing 10 species whereas Cucurbitaceae and Euphorbiaceae came next, each contributing ten and five species, respectively. The dominance of Asteraceae as a source of medicinal plant was reported by previous studies including Endalewu (2007), Seyoum (2009) and Sintayehu (2010).

Major diseases of the study area and their treatment

Informants reported 44 different ailments as human health problems. The most frequently cited eight diseases are malaria, pneumonia, skin diseases, stomach diseases, evil eye, intestinal parasites, typhoid and diarrhea (Appendix 1 and 3). On the other hand, 10 kinds of ailments are recognized as livestock diseases by local community members while anthrax, mastitis, pneumonia and ectoparasites are mentioned to be the major ones. When human and animal ailments are considered together, rabies, fire

burn, snake bite and evil eye turned out to be the major diseases of the area (Appendix 1, 2 and 3). As indicated in the previous section, a larger number of medicinal plants were used to treat human diseases when compared with livestock ailments. A study by Seyoum (2009) on medicinal plants in Debre Libanos Woreda of North Shewa Zone in Ethiopia yielded a similar result. This shows the greater reliance of local people of Bonke woreda on traditional medicine for treating their ailments than their livestock .This is associated with the proportional difference in the number of diseases reported to cause health problems in the two categories. However, other studies elsewhere in Ethiopia have reported an equal number of medicinal plants species to treat human and livestock aliments (Haile and Delnasaw, 2007; Ketema et al., 2013). This may be associated with the greater importance of livestock in the economy and socio-cultural aspects of those areas.

Plant parts used and mode of preparation

Different parts of medicinal plants are reported to have been used, either separately or in a mixture, for treating ailments. However, there is variation in the frequency of use of parts with the most dominantly used plant parts for remedy preparation being leaves, roots and seeds in the given order (Figures 2-4).

The most frequent use of leaves was also reported by previous studies (Bayafers, 2000; Mirutse and Gobana, 2003 and Tesfaye et al., 2009). While other studies like Mirutse (2007) and Ermias et al. (2008), mentioned the frequent use of roots as major items for remedy preparation. The fact that leaves are the most frequently used plant parts for the preparation of remedies might be associated with easier accessibility of the plant part as well as the abundance of active compounds in the primary photosynthetic organs. The wide harvesting of roots affects the survival, accessibility and sustainability of useful medicinal plants. On the other hand, the dominant use of leaves (that are readily available and regenerate easily) and also seeds (that are seasonally available and most often produced in abundance) has a lesser impact on the survival of mother plants and hence could be considered as a sustainable utilization practice.

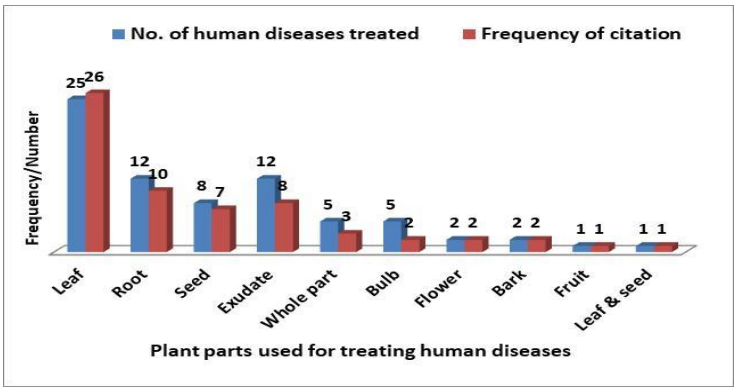

Figure 2. Citation frequency of plant parts used and number of human diseases treated by a plant part.

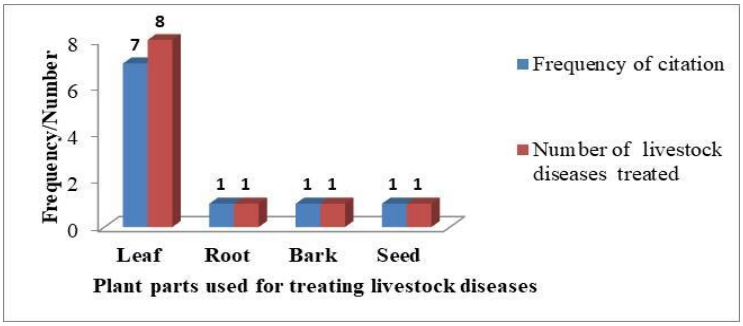

Figure 3. Citation frequency of plant parts used and number of livestock diseases treated by a plant part.

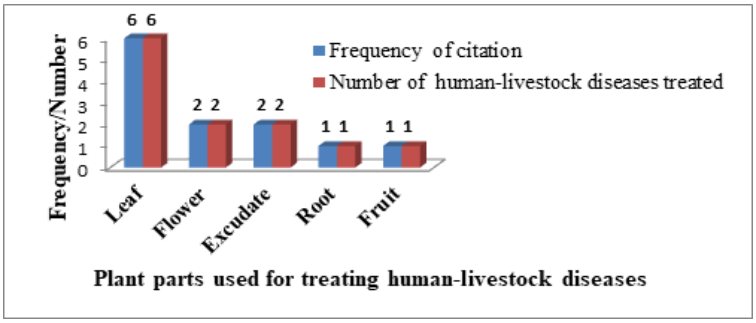

Figure 4. Citation frequency of plant parts used and the number of human-livestock diseases treated by a plant part.

As the study findings indicated, practitioners employ various methods of preparations of remedies for treating different ailments depending on the types of disease treated. Some of the remedies are mixed with different additives like butter, honey, sugar, wheat powder, water, *tella* (local beer) and milk that are meant to reduce the strength of the medicines and also improve the taste. The principal method of remedy preparation is pounding while other methods such as chewing, crushing, chopping, boiling and roasting are also used. Other studies (Sintayehu, 2010; Derebe, 2021; Mulugeta and Erchafo, 2017) have also reported similar results.

Route and dosage of administration

As verified by responses of community members involved in the study, remedies against illnesses are administered via different routes: oral, dermal, nasal, ear canal and anal (Figure 5). The top two most frequently used routes are the mouth and the skin, since in most cases, the remedies are either taken orally or smeared on the skin. Other studies conducted in different parts of Ethiopia also revealed that oral and dermal applications are the principal routes of remedy administration (Emiru et al., 2011; Samuel and Gidey, 2012).

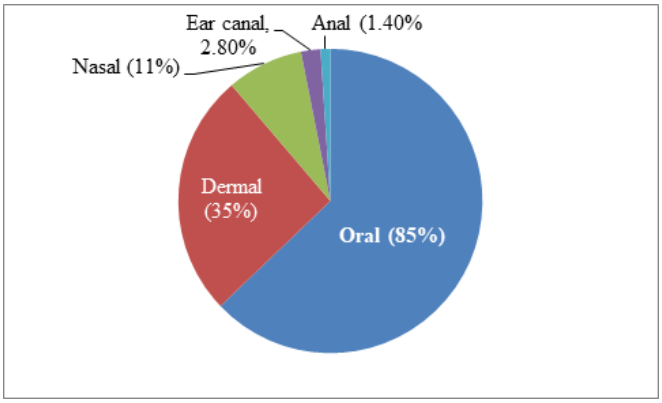

Figure 5. Proportion of respondents who cited the different routes of remedy administration.

As the gathered information indicated, the application of local medicine takes different forms such as drinking, chewing, topical application, sniffing, fumigating and tying the product on the body. This is in agreement with the findings of previous studies (Leul et al., 2018; Emiru, 2011; Sintayehu, 2010), that reported the use of different forms of administration with a varying degree of frequency.

Determining dosage when administering remedies is an aspect to which local healers and community members give attention. Accordingly, various units of measurement such as finger length (for root and bark), number (for seeds and flowers) and containers like cup (for decoction and infusion from plant parts) are used to estimate and fix the dosage of the specific medicine. While administering a medicinal product, dosage prescription is based on such factors as the age of the patients, the stage of illness or malignancy, pregnancy status, etc. A dosage is determined based on the experience of practitioners and healers. A higher or lower dose relative to the required amount is recognized to be not effective or may have negative side effects. Consulted traditional healers indicated that they use antidotes for any adverse effect caused by some medicinal preparations.

Agreement of Informants and their preference to Medicinal Plants

The Informant Consensus Factor (ICF) tool that was used to test agreement of informants on the use of medicinal plants for treating certain categories of diseases yielded different ICF values that ranged from 0.85 to 0.69 as indicated in Table 1. Accordingly, the utmost agreement of informants was displayed for four clusters of diseases: evil eye and evil spirit (0.8), malaria and typhoid (0.84), intestinal parasites, ascaris, tapeworm and hookworm (0.82) and eye-ear-teeth diseases (0.81). This high ICF values could be taken as indicative of the effectiveness of the medicinal plants used to treat diseases in the respective categories.

Table 1. Informant consensus factor by categories of diseases in the study area.

Diseases Categories	Spp.	Use citation	ICF
Evil eye, evil spirit	6	36	0.85
Malaria, typhoid	6	33	0.84
Intestinal parasite, ascaris, tapeworm, hookworm	6	30	0.82
Eye, ear and teeth disease	6	28	0.81
Wound, bleeding, infection, body swelling, fire burn Spider poison	10	45	0.79
Gastritis and stomach pain	15	65	0.78
Rabies and snake bite	4	15	0.78
Pneumonia, jaundice, common cold	10	38	0.75
Febrile illness, headache	4	12	0.72
Scabies, skin rash, tinea versicolor	4	12	0.72
Tonsillitis, goiter	5	14	0.69

To assess informants' preference of medicinal plants that were mentioned to have been used for treating stomach problems of human beings, a simple preference ranking test was conducted and the result is given in Table 2. Accordingly, *Ruta chalepensis* stood first as the most preferred medicinal plant to treat stomach disease; and this aligns with the attitude almost everywhere in Ethiopia to use the plant as a cure for stomach ailments.

Table 2. Preference ranking of medicinal plants used to treat stomach disease in humans (5 = the most preferred, 1 = the least preferred)

Medicinal plants	Informant (I) involved in ranking											
Ruta chalepensis	5	5	4	2	4	2	3	4	5	4	38	1st
Artemisia afra	4	3	5	3	5	5	2	3	4	1	35	2nd
Echinops kebericho	1	2	2	1	3	4	1	1	2	5	22	5th
Solanum incanum	3	4	3	5	2	3	5	2	3	2	32	3rd
Foeniculum vulgare	2	1	1	4	1	1	4	5	1	3	23	4th

Since diarrhea is among the prevalent health disorders in the study area, a paired comparison test of five medicinal plants that are used to treat the ailment was made by involving seven informants to rank them. The test result indicated that *Datura stramonium* is the much favoured plant in treating diarrhea (Table 3).

Table 3. Paired wise preference comparison of medicinal plants used to treat diarrhea.

Medicinal plants	Informant (I) involved in ranking								
	I1	**I2**	**I3**	**I4**	**I5**	**I6**	**I7**	**Total**	**Rank**
Artemisia absinthium	3	4	1	1	3	2	2	16	4th
Linum usitatissimum	2	1	3	2	2	4	3	17	3rd
Datura stramonium	3	2	3	4	2	4	4	22	1st
Achyranthes aspera	1	3	4	2	4	2	2	18	2nd
Ensete ventricosum	4	2	2	3	1	1	1	14	5th

Several woody plant species of medicinal importance are used for a variety of purposes such as construction, charcoal production, fencing, firewood and timber production. To assess the relative importance and check the popularity of these multipurpose plants, a direct matrix ranking analysis was conducted. In the process, five commonly reported multifunctional plant species and six use categories were employed and the ranking by five key informants yielded the result indicated in Table 4.

Table 4. Rank of five multipurpose woody plant species as determined by local preference.

Use category	Medicinal plants				
	Croton macrostachyus **(I_1-I_5)**	*Syzygium guineense* **(I_1-I_5)**	*Dodonaea angustifolia* **(I_1-I_5)**	*Erythrina brucei* **(I_1-I_5)**	*Vernonia amygdalina* **(I_1-I_5)**
Medicinal	25	17	20	16	25
Construction	12	19	25	7	7
Charcoal	9	12	18	11	8
Firewood	19	12	20	18	20
Timber production	10	10	5	7	4
Fencing	15	18	15	13	12
Total	90	88	103	72	76
Rank	2nd	3rd	1st	5th	4th

Accordingly, *Dodonaea angustifolia*, stood first as the most preferred species followed by *Croton macrostachyus* and *Syzygiumguineense*. The high preference dedicated to these species relates to the

quality of the wood in terms of resistance to weevil or termite attack, complete burning nature, suitability for timber production besides their use for medicinal purposes.

Source habitats of medicinal plants in the study area and their conservation status

As information gathered from local community members indicated, medicinal plants used for treating human and animal diseases are obtained from different sources. These include crop fields, farm edges, home gardens and wild vegetation (Figure 6). While home gardens and wild vegetation served as a source of medicinal plants used to treat human or animal or human-animal diseases, farm edges provided medicinal plants used to treat either human or animal ailments and crop fields supplied medicinal plants used to treat only human diseases. In terms of number of medicinal plants provided by each habitat type, home gardens provided the most (48%) followed by wild vegetation (40.3%) while farm edges and crop fields provided the least (6.5%) and (3.9%), respectively. Only one medicinal plant was reported to be collected from two habitats, i.e. crop fields and wild vegetation (Figure 6).

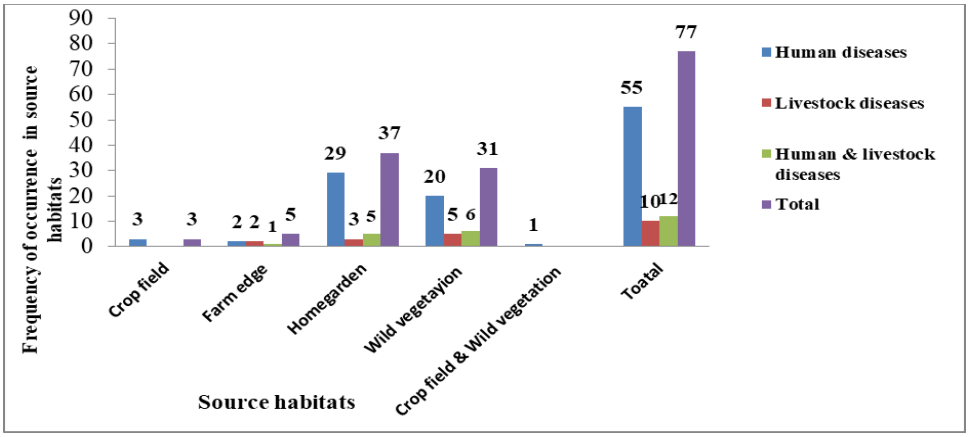

Figure 6. Occurrence of medicinal plants (used against different categories of diseases) in different source habitats.

The occurrence of the largest proportion of medicinal plants in home gardens must have been the result of their continuous incorporation from different sources (like markets and wild vegetation). This could be

taken as a positive situation since the maintenance of the medicinal resources under cultivation helped to ensure sustainability. The availability of medicinal plants in the wild provides an alternative source for accessing them. However, the rapid deterioration of vegetation cover because of land-use changes poses a serious concern regarding the sustainability of the resources. Churchyards and burial grounds covered by vegetation were observed to be important sites of medicinal plants' conservation since components plants are protected due to cultural and spiritual reasons. Such protection, in turn, contributes to the conservation of medicinal plants since cutting and harvesting are not allowed in such revered areas. The other conservation ethic related practice in the study area pertains to the norm of harvesting medicinal plants. In line with this, some local practitioners in the study area demonstrated a peculiar management practice when harvesting. Accordingly, practitioners take the most care when harvesting the root and bark of medicinal plants so as not to kill the resource plants. Only some portion of the bark or the root of the plant is taken and the rest is covered with soil or wrapped with some protective material to prevent the plant from dying.

Threats to medicinal plants and related local knowledge

Anthropogenic factors were identified as the main threats to medicinal plants in the study area. These include agricultural expansion associated with population growth, firewood collection, charcoal production and cutting of trees for construction. During field observations, people were spotted collecting firewood and timber (for house construction) by cutting shrubs and trees from the woodlands and forest patches. According to the traditional healers, it became difficult to collect medicinal plants in the area for the vegetation cover has continually diminished; and this forced the healers to travel long distances in search of resources. A ranking exercise that involved 10 respondents who ranked four factors in their perceived degree of importance (4 = with the greatest impact; 1= with the least impact) helped to order the threatening factors of local vegetation and medicinal plants as indicated in Table 5. Accordingly, agricultural expansion turned to be the most important factor that contributes to the loss of local

vegetation. The main threats for medicinal plants in the natural vegetation are, therefore, agricultural expansion and fuelwood collection. This result was in line with the report made by Zerhiun and Mesfin (1990) and Genene and Reddy (2015).

Table 5. Factors responsible for the loss of the local vegetation and medicinal plants in the study area.

Threatening factors	Respondents											
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**Total**	**Rank**
Agricultural expansion	4	4	4	4	4	4	4	4	4	4	40	1st
Construction	1	2	2	3	2	2	3	3	2	2	22	3rd
Firewood & Charcoal	3	3	3	2	3	3	2	2	2	3	26	2nd
Overgrazing	2	1	1	1	1	1	1	1	2	1	12	4th

Most of the knowledge on plant-based medicine is kept secret and held only by practitioners. Even when the medicinal products are administered, the practitioners somehow modify plant parts such as seeds and flowers by deforming their shapes so that they will not be recognized by an observer. The medicinal knowledge, when transferred, is passed only to selected close relatives. One quality that local healers require from a candidate whom they want to pass the medicinal knowledge is trustworthiness in keeping the information confidential. When transferring the knowledge, they remind the recipient to apply the same principle of secrecy. Maintaining secrecy of the knowledge is required as it is an important means of generating income for the family. Furthermore, it is believed that the healing skill which is granted by the almighty creator to the particular family line, as well as the healing power of the plant remedy, will likely be lost if the secret is not maintained. Due to this and other factors such as lack of interest by the young generations in traditional medication systems and the influence of modern education, local medicinal knowledge is confronted with a serious threat of loss.

CONCLUSION

The present study in Bonke Woreda of Gamo zone revealed that local community members rely on the use of traditional medicine for treating a wide range of human and livestock diseases. Though modern medicine is used to a limited extent, the use of diverse medicinal plants as a cure to local health problems is indicative of the well-developed traditional healthcare system of the community as well as the existence of a broad resource base. The tradition of frequently using leaves for remedy preparation could be viewed as a situation that allows sustainable utilization of medicinal resources. The expertise of traditional healers, which is demonstrated in the form of formulating remedies, prescribing appropriate doses, use of antidotes to neutralize unwanted impacts of medicinal preparation and preference of one medicinal plant over the other, is based on local knowledge accumulated over generations. However, the rich medicinal resources accessed from human managed ecosystems and wild vegetation, as well as the associated local knowledge are under threat of erosion, principally due to anthropogenic factors. Such trends, unless corrected in time, will ultimately affect the local people of the study area by disrupting their primary healthcare system. It is, therefore, appropriate to consider interventions that help conserve the medicinal plant resources of the area, the traditional medicinal practice as well as the associated knowledge.

ACKNOWLEDGMENTS

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Appendix 1. List of medicinal plants used for treating human diseases (B: Bark, Bu: Bulb, Cf: Crop field, Cl: Climber, Fe: Farm edge, Fl: Flower, Fu:Fruit, H: Herb, Hg: Home garden, L: Leaf, R: Root, La: Latex, Rz: Rhizome, S: Seed, Sa: Sap, Sh: Shrub, T: Tree, Tr: Trailer, Tu: Tuber, Wp: Whole plant, Wv: Wild vegetation, T: Tree).

No.	Scientific name	Family	Local name (Gamo)	Part Used	Habitat	Habit	Diseases treated	Route of Admin.
1	*Achyranthes aspera* L.	Amaranthaceae	Bitaerqa	L	Hg	H	Diarrhea	Oral
2	*Acmellacaulirhiza* Del.	Asteraceae	Fach facho	Fl	Hg	H	Tonsillitis	Oral
3	*Aframomum corrorima* (A.Braun) P.C.M. Jansen.	Zingiberaceae	Kororuma	S	Hg	H	Pneumonia	Oral
4	*Allium sativum* L.	Aliaceae	Tummo	Bu	Hg	H	Common cold, typhoid malaria, pneumonia	Oral
5	*Artemisia absinthium* L.	Asteraceae	Natira	L	Hg	H	Diarrhea	Oral
6	*Artemisia afra* Jacq. ex Willd.	Asteraceae	Chikugne	L	Hg	H	Stomachache	Oral
7	*Artemisia rehan* C.	Asteraceae	Artemisia	Wp	Hg	H	Malaria , pneumonia	Oral
8	*Basilicumpolystachyon* (L) Moench.	Lamiaceae	Takeso	L	Wv	Sh	Evil eye , evil sprit	Oral
9	*Brassica carinata*A.Br.	Brassicaceae	Gomenzere	S	Hg	H	Stomachache	Oral
10	*Carica papaya* L.	Caricaceae	Baqula	L & Fu	Hg	T	Intestinal parasites, malaria	Oral
							Gastric illness	
11	*Citrus limon* (L.) Burm. f.	Rutaceae	Lomee	Sa	Hg	Sh	Blood pressure, common cold	Oral
12	*Clematis simensis* Fresen.	Ranunculaceae	Asayfedhale	R	Hg	Cl	Evil eye (affecting pregnant women)	Oral
13	*Commelina petersii* Hassk.	Commelinaceae	Galgatsa	L	Hg	Rz	Evil eye	Oral
14	*Corchorus trilocularis*L.	Tiliaceae	Churja	L	Hg	H	Titanus	Dermal
15	*Coriandrum sativum* L.	Apiaceae	Dobe	S	Hg	H	Impotence	Oral
16	*Cressa cretica* L.	Convolvulaceae	Shosha dale	L	Wv	H	Snake bite	Dermal
17	*Croton macrostachyus* Del.	Euphorbiaceae	Badhite	La	Wv	T	Bleeding, skin rash	Dermal
18	*Cucurbita pepo* L.	Cucurbitaceae	Lelehe	L & S	Hg	Cl	Tapeworm	Oral
19	*Cymbopogon citratus (*DC.) Stap.	Poaceae	Chajesare	L	Hg	H	Pneumonia	Oral
20	*Datura stramonium* L.	Solanaceae	Mazho	L	Hg	H	Diarrhea	Oral
21	*Dioscorea alata* L.	Dioscoreaceae	Tura boye	L	Cf	Cl	Tinea versicolor	Dermal
22	*Echinopskebericho* Mesfin	Asteracea	Boroso	R	Fe	Sh	Stomachache	Oral
							Evil eye	Fumiga
							Tinea versicolor	Dermal

No.	Scientific name	Family	Local name (Gamo)	Part Used	Habitat	Habit	Diseases treated	Route of Admin.
23	*Endostemon tenuiflorus* (Benth.) M. Ashby.	Lamiaceae	Yezilat	Wp	Wv	H	Goiter, headache	Nasal
24	*Ensete ventricosum* (Welw.) Cheesman.	Musaceae	Utha	R	Hg	T	Typhoid, diarrhea	Oral
25	*Euphorbia breviarticulata* Pax	Euphorbiaceae	Akkirsa	La	Wv	T	Toothache	Oral
26	*Euphorbia candelabrum* Trémaux ex Kotschy.	Euphorbiaceae	Mathamitha	La	Wv	T	Gonorrhea, ascariasi, tooth ache	Oral
27	*Foeniculum vulgare* Miller Var.	Apiaceae	Katikala	R	Hg	H	Stomach ache	Oral
28	*Hagenia abyssinica* (Bruce) J.F. Gmel.	Rosaceae	Kosso	S	Fe & Wv	T	Tapeworm, hookworm	Oral
29	*Hypericum quartinianum* A.Rich.	Hypericaceae	Ereka	B	Wv	T	Stomach pain	Oral
30	*Isodon schimperi* (Vatke) J.K.Morton.	Lamiaceae	Mecha dale	L	Wv	Sh	Stomachache, sore lip	Nasal
31	*Jatropha curcas* L.	Euphorbiaceae	Tsedaki	La	Hg	Sh	Bleeding	Dermal
32	*Justicia flava* (Forssk.) Vah.	Acantaceae	Badalo	L	Hg	H	Amoeba	Oral
33	*Lepidium sativum* L.	Brassicaceae	Fetso	S	Hg	H	Skin disease, wound, tonsillitis	Dermal
34	*Moringa stenopetala* L.	Moringaceae	Halako	L	Hg	T	Blood pressure, malaria	Oral
35	*Myrtus communis* L.	Myrtaceae	Gazhiqano	R	Wv	T	Body swelling	Nasal
36	*Nigella sativa* L.	Ranunculaceae	Karetsaayfe	S	Hg	Sh	Pneumonia	Oral
37	*Ocimum lamiifolium* Hochst.	Lamiaceae	Mishatale	L	Hg	H	Sore tounge	Nasal
38	*Oliniarochetiana* A. Juss.	Olinaceae	Qaga	L	Wv	Sh	Toothache, jaundice	Oral
39	*Otostegia fruticosa* (Forssk.) Schweinf. ex Penzig.	Lamiaceae	Sosote	L	Hg	Sh	Stomach pain	Oral
40	*Phytolacca dodecandra* L'Herit.	Phytolaccacae	Hazinche	R	W	Sh	Jaundice, rabies, hyena bite	Oral
41	*Premna oligotricha* Baker.	Lamiaceae	Susa	Fl	Fe	Sh	Stomachache	Oral
42	*Premnaresinosa* (Hochst.) Schauer.	Verbenaceae	Ache dhale	R	Wv	T	Toothache	Oral
43	*Ranunculus simensis*Fresen.	Ranunculaceae	Gorethse	L	Wv	Sh	Internal parasite	Oral
44	*Rumex nervosus Vahl*	Polygonanceae	Chole	La	Fe	Sh	Skin disease	Dermal
45	*Ruta chalepensis L.*	Rutaceae	Tsalado	L	Hg	H	Stomachache, evil eye	Oral
46	*Solanum incanum L.*	Solanaceae	Bundo	R	Wv	Sh	Stomachache	Oral
47	*Syzygiumguineense (Willd.) DC.*	Myrtaceae	Oche	L	Wv	T	Pneumonia, tonsillitis, sour tounge, typhoid, stomach ache	Oral
48	*Tagetes minuta L.*	Asteraceae	Tunga	L	Wv	Sh	Pneumonia	Oral
49	*Thymus schimperi Ronniger*	Lamiaceae	Zimpha	Wp	Hg	H	Stomach ache	Oral

No.	Scientific name	Family	Local name (Gamo)	Part Used	Habitat	Habit	Diseases treated	Route of Admin.
50	*Triticum aestivum L.*	Poaceae	Giste	S	Fe	G	Spider poison	Dermal
51	*Vernonia bipontini Vatke.*	Asteraceae	Kacheta	R	Wv	Sh	Delayed placental delivery	Oral
52	*Vernonia hochstetteri Sch. Bip. ex Walp.*	Asteraceae	Buzo	L	Wv	Sh	Stomach ache	Oral
53	*Zehneria anomala C. Jeffrey.*	Cucurbitaceae	Kurkuchi	R	Wv	Cl	Rabies	Oral
54	*Zehneriascabra (Linn.f.) Sond*	Cucurbitaceae	Shoshadhale	L	Wv	Cl	Snake bite	Dermal
55	*Zingiber officinale Roscoe*	Zingiberaceae	Jenjelo	Bu	Hg	H	Common cold, tonsillitis	Oral

Appendix 2. List of medicinal plants used for treating livestock ailments (B: Bark, Bu: Bulb, Cf: Crop field, Cl: Climber, Fe: Farm edge, Fl: Flower, H: Herb, Hg: Home garden, L: Leaf, R: Root, La: Latex, Rz: Rhizome, S: Seed, Sa: Sap, Sh: Shrub, T: Tree, Tr: Trailer, Tu: Tuber, Wp: Whole plant, Wv: Wild vegetation, T: Tree).

No.	Scientific name	Family	Local name	Part Used	Habitat	Habit	Diseases treated	Route of admin.
1	*Brucea antidysenterica*	Simaroubaceae	Mehe dhale	L	Wv	Sh	Ticks	Dermal
2	*Cyphostemma cyphopetalum* (Fresen.) Desc. ex Wild & R. B. Drumm.	Vitaceae	Dodhe	R	Hg	H	Evil eye	Oral
3	*Dodonaea angustifolia* L. f.	Sapindaceae	Sagira	L	Wv	Sh	Stomach disorder	Oral
4	*Erythrina brucei* Schweinf.	Fabaceae	Kore	L	Wv	T	Ticks	Dermal
5	*Premna schimperi* Engl.	Lamiaceae	Hafra	L	Fe	Sh	Diaharea	Oral
6	*Ricinus communis* L.	Euphorbiaceae	Gulo/Qobbo	S	Hg	Sh	Anthrax	Oral
7	*Salix subserrata* Willd.	Salicaceae	Bola dhale	L	Wv	T	Physical weakening	Oral
8	*Tetrapanax papyrifera* (Hook.) K. Koch	Araliaceae	Hatsa	B	Fe	Sh	Mastitis	Oral
9	*Vernonia adoensis* Sch. Bip. ex Walp	Asteraceae	Gingina	L	Wv	T	Cough, Constipation	Oral
10	*Vernonia amygdalina* Del.	Asteraceae	Gara	L	Hg	T	Internal parasite	Oral

Appendix 3. Medicinal plant species used for treating both livestock and human ailments (Cl: Climber, F: Fruit H:Fl:Flower, Herb, Hg: Homegarden, L: Leaf, La: Latex, R:Root, Sa: Sap, Sh: Shrub, T: Tree Tu: Tuber, Wp: Whole plant, Wv: Wild vegetation, T: Tree).

No.	Scientific name	Family	Local name	Part Used	Habitat	Habit	Diseases treated	Route of admin.
1	*Aloe* spp.	Aloaceae	Godareuutha	La	Hg	H	Fire burn	Dermal
2	*Clausenaanisata (*Willd.) Hook.f. ex Benth.	Rutaceae	Alga	L	Hg	Sh	Skin rash	Dermal
3	*Cressa arabica* Forssk.	Convolvulaceae	Shoshadhale	L	Wv	Cl	Snake bite	Dermal
4	*Cucumis ficifolius*A.Rich.	Cucurbitaceae	Phirifithi	Fl	Hg	Cl	Ear pain	Ear canal
5	*Cucumis zeyheri* Sond.	Cucurbitaceae	Kurkuchi	R	Wv	Cl	Rabies	Oral
6	*Ekebergia capensis* Sparrm.	Meliaceae	kintsipile	Sa	Wv	T	Hemorrhoid	Anal
7	*Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae	Bita wororo	Fl	Wv	Cl	Malaria	Oral
8	*Leucas urticifolia* (Vahl) Sm.	Lamiaceae	Olge	L	Fe	H	Constipation	Oral
9	*Linum usitatissimum* L.	Linaceae	Tura	S	Hg	H	Diaharea	Oral
10	*Lippia adoensis* Hochst. ex Walp. var. koseret Sebsebe	Verbenaceae	Chozhe	L	Wv	Sh	Skin rash	Dermal
11	*Ocimum gratissimum* L.	Lamiaceae	Mimicho	L	Hg	H	Febrile illness	Nasal
12	*Plantago lanceolata* L.	Plantaginaceae	Yezale	L	Wv	H	Wound	Dermal

IMPACT OF CLIMATE CHANGE ON THE SPATIAL DISTRIBUTION AND PRODUCTIVITY OF *COFFEA ARABICA* L. IN AFRICA: A REVIEW

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ABSTRACT: Coffee is a fundamental export commodity of many African countries. Despite its importance for the national economy of countries, its production and productivity are predicted to be negatively affected by climate change. This review aimed to synthesize the observed and anticipated impacts of climate change on the distribution and productivity of Arabica coffee. To this end, a systematic review of literature was employed. The evidence showed that suitable areas for Arabica coffee cultivation will diminish by 60% by 2050 and vanish at the end of the 21st in Africa if the business as usual scenario continues and interventions are not taken in time. The productivity of coffee has been declining and is predicted to decline substantially (25-60%) by 2050 in Africa. Consequently, the livelihood of smallholder producers and the economy of coffee growing countries are at risk and under a vicious circle of poverty. Furthermore, the African share of the world's Arabica coffee production has been declining with a current share of 12% calling for increasing productivity and ensuring benefit-sharing through securing sustainability and value additions. As climate changes, the currently suitable area for coffee production declines, and shifts to highlands. Consequently, conflicts over land use priorities and deforestation for coffee cultivation will cause the loss of biodiversity. Mainstreaming biodiversity in the coffee production system, interventions for climate change adaptation and mitigation as well as promoting in-situ conservation of the coffee gene pool are important to ensure sustainable utilization of genetic resources.

Keywords: Biodiversity, Climate change, *Coffea arabica*, Conservation.

INTRODUCTION

Coffee is one of the most important global plant genetic resources as it has been playing a significant role in the economy of both producing (DaMatta et al., 2008) and consuming countries (UN, 2018).

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Coffee is produced in more than 80 countries (Ramalho et al., 2013), out of which more than 50 countries have been exporting a substantial amount of their production to the global market (Szenthe, 2019). Globally, coffee supports the livelihoods of more than 25 million people (DaMatta et al., 2008; UN, 2018). *Coffea arabica* L. (Arabica coffee) and *Coffea canephora* Pierre ex A.Froehner (Robusta coffee) are the most widely consumed cash crops (DaMatta et al., 2008) and pharmacologically active beverages (Chen, 2019). Coffee consumption has become a regular part of daily life in the world (UN, 2018). The Arabica coffee is widely consumed and it is by far the dominant bean used in the world (DaMatta et al., 2008), representing about 60% of the total global production in the last five years (USDA, 2019a). In Ethiopia, coffee is an integral part of the socio-cultural value of people in its land of origin. Ethiopian uses coffee for a family gathering, spiritual celebration, marriage ceremony, conflict resolution, during gatherings for farming and mourning.

All global coffee productions are from the equatorial region (coffee belt or coffee-growing zone) of Central and South America, Southeast Asia and Africa (Szenthe, 2019). South America is leading the global market with the largest share of Brazil and Colombia (Iscaro, 2014). Asian countries are also famous for their rich coffee production with earthy and light flavours (Szenthe, 2019).

Africa is the homeland of both Arabica coffee and Robusta coffee (Melke and Fetene, 2014; Bunn et al., 2015; Ovalle-Rivera et al., 2015) and is known for its best coffee flavour and aroma in the world (ICO, 2015; Ovalle-Rivera et al., 2015; UN, 2018). Among other crops, Arabica coffee is a fundamental commodity in Africa (Lemma and Megersa, 2021) and the backbone of Ethiopia's economy (Iscaro, 2014).

Studies show that Arabica coffee is predicted to be significantly affected by climate change (Aerts et al., 2017; Craparo et al., 2015; Hirons et al., 2018). In this regard, Africa is the most vulnerable continent to the negative impacts of global climate change (IPCC, 2014). The temperature of the continent has increased by 0.7^{o}C in the 20th century and is expected to continue warming with a range of 0.2^{o}C (B1 scenario) - 0.5^{o}C (A2 scenario)/ decade during the 21st century (IPCC, 2013). The pattern of rainfall was irregular and erratic in the main coffee-growing countries (Moat et al., 2017). As

climate change is predicted to continue in the coming decades, it is expected that the production of Arabica coffee will be altered abundantly in the continent (Davis et al., 2012; Agegnehu et al., 2015; Bunn et al., 2015; Abrha, 2018). Consequently, the livelihood of millions of smallholder producers in the continent, the share of GDP and employment of the producing countries will be highly affected. As a result, the development of the continent and the wellbeing of the human being at large will be subjected to dependency, unless remedial actions are taken in advance.

Despite many research results on coffee (Davis et al., 2012; Bunn et al. 2015; Ovalle-Rivera et al., 2015; Moat et al., 2017), the understanding about the impact of climate change on Arabica coffee is still limited and demanding in Africa (Craparo et al., 2015). Therefore, understanding how and to what extent climate change affects the spatial distribution and productivity of Arabica coffee is important to set adaptation and mitigation strategies for the sector and smallholder producers in the continent (Bro et al., 2019). To this end, this review aimed at compiling and analysing existing information and data on the impact of climate change on the spatial distribution and productivity of Arabica coffee in Africa for influencing decision making processes related to the management of coffee production and its natural ecosystems in the face of changing climate. This review will contribute to the on-going scientific and policy debates on the interplay of coffee, climate change and resilience of stakeholder's livelihoods in developing countries.

METHODS

This review targeted at the major coffee-growing countries in Africa. These countries are mainly situated in the tropics including Burundi, Cameroon, the Democratic Republic of Congo, Ethiopia, Kenya, Madagascar, Malawi, Rwanda, Tanzania and Uganda. They share about 80% of the annual coffee production of Africa (ICO, 2015; UN, 2018; USDA, 2019a).

The data were obtained from different databases and empirical studies to show the impact of climate change on the spatial distribution of coffee production and productivity in the major coffee-growing countries in Africa. The raw data about annual Arabica coffee production and global market share of

Africa by country were accessed from International Coffee Organization (ICO) following an official request.

The search for available literature was carried out systematically. Google scholar, Agora and Science direct have been used as the main database for searching different kinds of literature including books and journal articles. The Boolean searching technique was employed using both "and" and "or" operator with a wide range of keywords such as coffee, coffee production, coffee productivity, coffee and climate, *Coffea arabica*, deforestation, climate change, biodiversity and Africa. Accordingly, a total of 5269 papers (5242 published articles and 27 unpublished) were accessed (Figure 1). All accessed studies were screened by title by raising and answering the basic question for each paper; which is - Does the paper have vital information or evidence to support the objective of this study? Those papers which got a "yes" response were selected for further review. Accordingly, a total of 132 papers were left for abstract review. These selected studies were further screened by their abstract, and papers with having very limited information were screened out. Then, a total of 49 papers were fully reviewed and sufficient data were extracted from all selected studies and synthesized. The data obtained from the different sources were analysed using descriptive statistics.

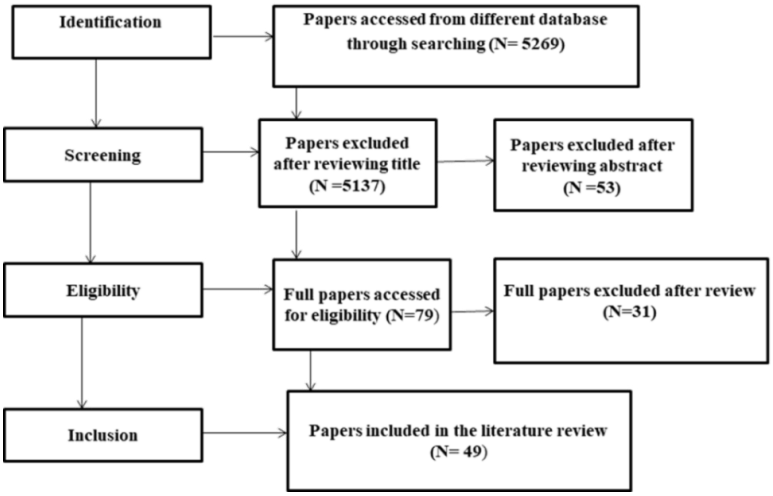

Figure 1. Flow chart of review process and number of literature reviewed adopted from (Pham et al., 2019), N: number of papers.

RESULTS

Current status of coffee production in Africa

The continent of Africa has the highest number of coffee-producing countries in the world (UN, 2018). The International Coffee Organization report indicates that about 25 African countries are producing coffee (ICO, 2015), out of which 10 are producing a significant proportion (about 80% of the continent's production) of Arabica coffee in the last decade (Table 1; Table 2).

Table 1. Arabica coffee Production (1000 x 60-Kilogram Bags) in high producing countries of Africa (2010-2020).

Country	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20	Average	Share of the country(%)
Burundi	235	210	235	185	160	240	200	205	200	200	207.0	2.19
Cameroon	90	90	50	50	50	50	50	50	50	50	58.0	0.61
DR Congo	100	90	80	70	70	70	70	75	70	75	77.0	0.82
Ethiopia	6,125	6,320	6,500	6,345	6,475	6,510	6,943	7,050	7,250	7,350	6,686.8	70.89
Kenya	710	750	660	850	750	750	815	715	775	775	755.0	8.00
Madagascar	25	25	25	25	25	25	25	25	30	25	25.5	0.27
Malawi	24	21	25	25	21	23	16	12	11	10	18.8	0.20
Rwanda	317	245	260	250	240	300	230	275	275	300	269.2	2.85
Tanzania	600	365	610	450	600	600	550	600	700	650	572.5	6.07
Uganda	644	875	800	850	750	750	1200	750	800	750	816.9	8.66
Total	8,870	8,991	9,245	9,100	9,141	9,318	10,099	9,757	10,161	10,185	9,486.7	100

Source: USDA, 2019a.

In terms of global Arabica coffee production, the share of African is on average estimated at 12% (Table 1) and this supports the livelihood of more than 25 million smallholder farmers (ICO, 2015; UN, 2018; USDA, 2019a). In Africa, a large number of people depend on coffee growing, processing and marketing for livelihood support (UN, 2018). Coffee contributes to the employment of about five million people in Kenya (ICO, 2019). Besides, coffee contributes significantly to the national economy or GDP of coffee-producing Africa countries (DaMatta et al., 2008). However, the share of Africa in the global market is small and has been declining (ICO, 2015; USDA, 2019a).

Table 2. Average yield and coffee farming area in Africa.

	2010/11		2015/16		2019/20	
Country	**Area(ha)**	**Yield(Kg/ha)**	**Area (ha)**	**Yield(Kg/ha)**	**Area(ha)**	**Yield(Kg/ha)**
Burundi	60,000	281	60,000	258	60,000	200
Cameroon	140,000	220	140,000	214	140,000	130.5
DR Congo	200,000	101	200,000	74	200,000	75
Ethiopia	509,000	800	509,000	837	509,000	866.4
Kenya	160,000	412	160,000	281	160,000	291
Madagascar	200,000	222	200,000	233.7	200,000	86.5
Malawi	3,500	185	3500	184	3,500	184
Rwanda	42,000	500	42,000	429	42,000	429
Tanzania	229,000	216	275,000	170	275,000	273
Uganda	282,284	708	282,000	1,042	282,000	904.26
Others	569,184	-	523,184	-	523,184	-
Africa	2,440,684	408.5	2,440,684	384	2,440,684	368

Source: ICO, 2015; UN, 2018; USDA, 2019a.

Ethiopia, the center of origin for Arabica coffee, is the leading producer and exporter in Africa (Table 2) and ranked fifth in the world (UN, 2018). Out of 6,686,800 of 60-Kilogram bags annual average production (Table 1), Ethiopia exported 55% of total production to the global market. The rest was consumed in the country. The economy of Ethiopia largely depends on the production of Arabica coffee, which accounts for about 30% of total export earnings and 5% of GDP (USDA, 2019b).

In Africa, Uganda is the second-largest exporter of Arabica coffee accounting for 5% of GDP and employ about one million people in the country (Ahmed, 2012). Kenya is also another major producer of Arabica coffee. The Kenyan coffee sector is annually worth about 230 million US dollars in foreign exchange earnings. Tanzania is the fourth producer and exporter of Arabica coffee during the last decade (Table 1). Burundi, Rwanda, the Democratic Republic of Congo, Cameroon, Madagascar and Malawi are among the producer and exporter countries of Arabica coffee in the continent. In these countries, the dependency of smallholder farmers on coffee production has been increasing. The coffee sector contributed to 59% of the earnings of foreign exchange in Burundi (Ovalle-Rivera et al., 2015). In Malawi, the production share of smallholder farmers has increased from 2.6% in 1999 to 15.7% in 2007. In Rwanda, the economy of the nation and livelihood of 500,000 smallholder households which

corresponds to 2 million people (i.e. 25% of the total population) depend on Arabica coffee production (Hakorimana and Akcaoz, 2017).

Effects of climate change on spatial distribution of Arabica coffee in Africa

The MaxEnt model prediction indicates that the currently suitable area for coffee cultivation will be reduced by 60% in the mid of 21st century (Davis et al., 2012; Ovalle-Rivera et al., 2015). As a result, Uganda and Tanzania will lose the currently suitable area below 1400 m a.s.l. Madagascar sub-region is predicted to lose its entire Arabica coffee growing area in the low attitudes (<1400 m a.s.l) (Ovalle-Rivera et al., 2015). Zimbabwe is expected to lose about 30,000 to 50,000 ha of currently suitable area for Arabica coffee production by 2050 (Chemura et al., 2015). The current Arabica coffee production areas in some East African countries including Ethiopia, Uganda and Kenya will shift to highlands by the end of 2050 (Bunn et al., 2015; Ovalle-Rivera et al., 2015).

Despite some discrepancies in the efficiency of prediction, if the predicted scenarios of climate change unfold, the suitable area for Arabica coffee production in Africa will diminish from the current 24,406 Km^2 to 7,708 Km^2 in mid of 21st century (Davis et al., 2012; Ovalle-Rivera et al., 2015).

Effects of Climate Change on Productivity of Arabica coffee in Africa

The global demand for Arabica coffee has been increasing (ICO, 2015; UN, 2018). Regardless of the commitment of the producer and other stakeholders to scale up the productivity, the current and future production of Arabica coffee will not satisfy the growing demand of the global market. The average annual production is declining in contrast to the rising demand (UN, 2018) and exhibits decline over the last five decades in Africa (ICO, 2015). The evidence depicts that coffee productivity of the continent has been declining, except in Uganda and Ethiopia (Table 2) and is predicted to decline substantially in the coming decades (Davis et al., 2012; Chemura and Kutywayo, 2015; Gidey et al., 2019; Ngango and Kim, 2019).

It is predicted that some of Arabica coffee-producing countries in Africa lost their total production at the beginning of the 21st century (ICO, 2015). It was showed that Angola had the potential of annual

average production of 2.4 million Kg of Arabica coffee at the end of the 20th century. A review of different data showed that Angola has lost its 99% Arabica coffee production in 2003 (ICO, 2015; USDA, 2019a). Zambia had produced 4.73 million kg of Arabica coffee annually at the beginning of the 21st century. However, it has lost its significant production since 2011. Similarly, Zimbabwe had the potential of 5.046 million Kg of average annual Arabica coffee production, which has been largely lost in 2010. The Democratic Republic of Congo and Madagascar had also lost their historical significant global market share (ICO, 2015).

DISCUSSION

Coffee is highly sensitive to temperature and rainfall (DaMatta et al., 2008; Davis et al., 2012; Bunn et al., 2015; Magrach and Ghazoul, 2015). The climate change prediction indicates that the entire continent of Africa will warm in the coming decades with 0.2-0.5°C per decade with erratic rainfall (IPCC, 2013). The previous studies categorize the Arabica coffee growing regions of Africa into two sub-regions: The East African sub-region and the Madagascar sub-region (Ovalle-Rivera et al., 2015). In most parts of Arabica coffee producing countries of the East African sub-region, the annual rainfall is predicted to be reduced in the coming decades (IPCC, 2013). Consequently, substantial size of the currently suitable land area for Arabica coffee cultivation will be reduced (Davis et al., 2012; Ovalle-Rivera et al., 2015) with the narrow optimum temperature range (18 to 22°C) required for its cultivation (DaMatta et al., 2008; Moat et al., 2017) and variable rainfall distribution (Magrach and Ghazoul, 2015).

As the suitable land area continues to decline, farmers will be forced to migrate to the high altitude areas of coffee growing regions for cultivation (Ovalle-Rivera et al., 2015). In the Madagascar sub-region, the range will shift upward from 500-1700 to 700-2000 m a.s.l (Ovalle-Rivera et al., 2015). In the East Africa sub-region, the suitable climate for Arabica coffee production will be shifted upward from 400-2000 m a.s.l to 800-2500 m a.s.l. However, difficulties in high elevation areas including the steep slope, shallow soil depth, too cold temperature and soil of mountainous cultivation challenge the upward migration strategy (Bunn et al., 2015).

Most likely, the projected suitable areas in East Africa sub-region overlap with currently registered and designated biodiversity hotspots (Magrach and Ghazoul, 2015) where originally coffee was found (DaMatta et al., 2008). This leads to land use conflict by putting deforestation on natural forest resources found in high altitudes (Rahn et al., 2013). The expansion of coffee production in this region will have positive feedback both on climate change and the reduction of suitable land areas for coffee production (Davis et al., 2012; Magrach and Ghazoul, 2015). Moreover, this would lead to the loss of 35% of local biodiversity (Magrach and Ghazoul, 2015) including wild Arabica coffee (Davis et al., 2012; Moat et al., 2017). As a result, the current coffee growing and predicated suitable land area will be substantially decreased at the end of the 21st century (Moat et al., 2017; Davis et al., 2012).

Although there are some discrepancies on the projection of suitability of future land area, all studies (Davis et al., 2012; Bunn et al., 2015; Ovalle-Rivera et al., 2015; Moat et al., 2017) confirm that the overall impact of climate change is predicted to be negative in Africa. This affects farmers and all actors in the value chain of coffee marketing (Haggar and Schepp, 2012). Consequently, the livelihoods of about 25 million people who directly or indirectly depend on coffee might be at great risk (UN, 2018). This figure is expected to be doubled by 2050. The national GDP and foreign currency earnings of the countries will also be seriously affected.

As the suitable area continues to decline, the Arabica coffee population is expected to be stressed and reduced (Andrade et al., 2019; Gidey et al., 2019; Justine et al., 2019) with the high risk of extinction at the end of the 21st century. The prediction of previous studies indicated that the unsuitability of the bioclimatic factor for the Arabica coffee population leads to total extinction from its original habitat at the end of this century (Davis et al., 2012). The observed and anticipated evidence pinpoints that the Arabica coffee population is highly vulnerable to extinction at the end of the 21st century (Davis et al., 2012; Moat et al., 2019). The MaxEnt model-based prediction also indicates that the population of wild Arabica coffee will be reduced by 80% by 2088, if precautionary measures are not implemented in advance (Davis et al., 2012; Moat et al., 2019). Even in a managed system, the prevalence of sudden shocks of climate change such as drought, an outbreak of pests and disease causes the mortality of

Arabica coffee soon (Drinnan and Menzel, 1995; Jaramillo et al., 2013; Agegnehu, 2015; Aerts et al., 2017; Moat et al., 2017; Liebig et al., 2018). During the continuous oscillation of drought, the vulnerability of Arabica coffee was reported in different parts of coffee growing regions in Africa (Lemma and Megersa, 2021; Merga and Alemayehu, 2019).

Climate change, among many other factors, hinders the production of Arabica coffee in the continent of Africa (Jaramillo et al., 2011; Davis et al., 2012; Jaramillo et al., 2013; Chemura et al., 2015; Gidey et al., 2019). Humidity, rainfall, and temperature considerably determine coffee production and productivity (DaMatta et al., 2008; Davis et al., 2012; DaMatta et al., 2018). The Arabica coffee needs a less humid atmosphere, comparable to Ethiopian highlands (DaMatta et al., 2008).

Rainfall affects the phenology and consequently the productivity of coffee. The Arabica coffee cultivation requires high rainfall in the range of 1200 to 2000 mm per year (Melke and Fetene, 2014; Bunn et al., 2015). However, excess rainfall during the flowering season alters its flowering. In the main coffee-growing regions of eastern Africa, the rainfall has decreased during the coffee-growing season by 15% in the last 30 years (Moat et al., 2017). Hence, unreliable, erratic and short rainfall season has posed unanticipated challenges on the patterns of cherry ripening in most coffee-growing countries (ICO, 2019).

Arabica coffee is highly sensitive to increasing temperature during blossoming and fructification (Haggar and Schepp, 2012). The optimum temperature of Arabica coffee is 18-22°C (Moat et al., 2017). The average temperature beyond 23°C hinders the growth and ripening of the coffee cherries. Temperature about 28-30°C alters flowering and fruit formation (Drinnan and Menzel, 1995). The continuous exposure to daily temperatures above 30°C leads to the loss of the leaves. Beyond 33°C the survival of the crop might be largely challenged and leads to slaying the crop (Drinnan and Menzel, 1995). If the other factors are constraints, Arabica coffee can gradually survive temperatures as high as 37/30°C (day/night) (DaMatta et al., 2018). However, the yield is not expected. On the other hand, temperature below 18°C depressed the growth of coffee. The enhanced temperature leads to water

stress and affects the physiology of Arabica coffee and ultimately limits photosynthesis (Haggar and Schepp, 2012). Productivity is entirely governed by the efficiency of photosynthesis.

The modeling study in Tanzania indicated that temperature rise in +1°C is predicted to reduce productivity of coffee by 25.3% (equivalent 397, 834 ton/year), +3°C reduce by 68.8% (1,081,856 ton/year), +5°C reduce by 96.6% (1,519,001 ton/year) (Haggar and Schepp, 2012). Other studies in the same country also predicted that the productivity of Arabica coffee might decline by 145 Kg/ha by 2060 (Craparo et al., 2015). Furthermore, a study in Ethiopia showed that the productivity of Arabica coffee will be reduced by 4-25% and 20-60% in shading and without shading systems, respectively in the faces of climate change (Gidey et al., 2019). In contrary to projections made so far, the productivity of Ethiopian coffee had shown an increasing trend (0.74 ton/ha in 2015/16 to 0.82 ton/ha in 2029/20) in the last five years (USDA, 2019b). Some scholars argue that enough rainfall and optimum temperature in most coffee-growing areas of the country contributed to the increasing production (USDA, 2019b). Other scholars argued that intensive management practices including shading contributed to sustaining coffee productivity (Moat et al., 2017). The latter group claims that climate change would significantly reduce the productivity of coffee if intensive management is not done in advance.

The prevailing expansion of pests and diseases (Ngango and Kim, 2019) in association with climate change also imposed challenges on Arabica coffee production and productivity in Africa (Hirons et al., 2018). The coffee berry borer (*Hypothenemus hampi* Ferrari) that attacks Arabica coffee (Agegnehu et al., 2015; Liebig et al., 2018) was originally found in the low altitudes (<1400 m a.s.l) of Central Africa. However, this pest had moved upward to the high elevations (>1800 m a.s.l) in east Africa (Agegnehu et al., 2015). As a result of climate change-induced pest and disease expansion (Weldemichael and Teferi, 2019), the current Arabica coffee production areas in Ethiopia, Uganda, Kenya, Rwanda and Burundi are expected to be significantly infested by 2050 (Jaramillo et al., 2011; Agegnehu, et al., 2015). Consequently, the observed and anticipated outbreak of pests and disease would reduce the productivity of coffee in Africa (Hirons et al., 2018).

The interaction of coffee and pollinators is also highly affected by climate change (Imbach et al., 2017). The distribution of pollinators mainly honey bees and butterflies govern the productivity of coffee farming (Ngo et al., 2011). As both pollinators and coffee are sensitive to climate change, the future common/ intersection area is predicted to decline (Abrha, 2018). Ultimately, the productivity of coffee farming is expected to be hindered in Africa. Thus, the livelihood of millions of smallholder coffee producers who substantially depend on coffee production will be challenged and pushed into a vicious circle of poverty (ICO, 2015).

CONCLUSION

Coffee is one of the most important crops in Africa and has a high contribution to the national economy of producer countries. However, the production of Arabica coffee has been affected and predicted to be affected by climate change. The spatial coverage of the currently suitable area for Arabica coffee cultivation will diminish by 60% by 2050 and vanish at the end of the 21st century in Africa. As climate change continues the cultivation of Arabica coffee will move upward to high altitudes. This, in turn, puts pressure on internationally recognized and conserved biodiversity hotspot areas and raises conflicts over land use priorities in some coffee-growing countries in Africa. As a result, deforestation for coffee cultivation will cause local biodiversity loss including wild Arabica coffee from its in-situ conservation area. This also leads to the total extinction of Arabica coffee genetic diversity and population from its original habitat at the end of the 21st century.

Climate change-induced drought, an outbreak of pests and disease caused the mortality of Arabica coffee in the last decades and is predicted to continue in the forthcoming decades. The productivity of coffee has been declining and is predicted to decline substantially (25-60%) by 2050 in Africa. Consequently, the livelihood of smallholder producers and the economy of the growing countries are at risk and under a vicious circle of poverty in Africa.

RECOMMENDATION

An innovative approach in coffee farming to scale up adaptation capacity and mitigation measures would play a significant role to sustain coffee and coffee production. Coffee agroforestry is one of the

promising strategies to sustain coffee production and biodiversity conservation in the face of changing climate. In-situ conservation of Arabica coffee gene pool in its natural/original habitat is important to maintain the genetic resource, yield and yield stability across coffee growing regions in the world. Therefore, it is vital to strengthen the in-situ conservation of coffee gene pool to ensure sustainable utilization of genetic resources.

Moreover, despite its recalcitrant nature, biotechnology-based ex-situ conservation has to be integrated as a complementary approach for enhancing the conservation of the diverse gene pools of this important crop. Mainstreaming and integrating biodiversity conservation into the coffee production system and promoting adaptation and mitigation strategies for climate change are important.

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Short communication

EVALUATION OF GERMINATION PRETREATMENT AND COMPOSITION OF SOME NUTRIENTS IN *ERIOSEMA CORDIFOLIUM*: AN OVERLOOKED WILD EDIBLE PLANT IN ETHIOPIA

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ABSTRACT: *Eriosema cordifolium* (Hochst. ex A. Rich.) is a wild edible plant that belongs to the Fabaceae family. Its tuber is harvested from the wild for local use as food and consumed raw as a snack especially by children. However, no study was yet undertaken on its seed germination and nutritive values which are among the requirements useful for its conservation and utilization. The aim of this preliminary study is thus to investigate the germination pretreatment and nutritive value of *E. cordifolium*. The germination requirement was studied using four different methods: using sand substrata and keeping in the oven at 33°C, soaking in cold water for 24 hrs, soaking in hot water (70°C) for 15 minutes and applying mechanical scarification. For nutrition analysis, dried tubers were ground into powder and crude fat, mineral ash and moisture content were analyzed in replicates following standard methods. The germination tests showed that mechanical scarification is the most promising method which resulted in 65% of seed germination. The result of the nutritional analysis showed an average crude fat content of 0.55%, ash content of 6.05% and 16.59% moisture content. The findings reported here could lay the basis for further research on the species.

Keywords: *Eriosema cordifolium*, Germination, Pretreatment, Nutrition.

INTRODUCTION

Wild edible plants are plant species that are neither cultivated nor domesticated but are used as a source of food from their wild natural habitat (Beluhan and Ranogajec, 2010). They have significant importance in supplementing staple foods and filling food gaps. As a result, their loss could cause food insecurity and imbalance. The genus *Eriosema* is pantropical and comprises about 150 species distributed mainly in Africa (110 species) and America (38) (Schrire, 2005). As reviewed by Selepe (2011) the genus Eriosema have several ethnomedicinal uses and have been used in treatments of

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ailments such as diarrhea, orchitis and hydrophobia. The isolated flavinoides and derivatives also have several pharmacological properties which include antimicrobial, cytotoxicity, antioxidant, antiviral, erectile-dysfunction, vasodilatory and hypoglycemic (Awouafack et al., 2015).

Eriosema cordifolium (Hochst. ex A. Rich.) which belongs to the Fabaceae family and known by its common name *Qurqufo* in Afaan Oromo, is an overlooked wild edible plant in Ethiopia. It grows within altitudinal ranges of 1700 – 2500 m a.s.l. and was reported from Northwest Ethiopia, Shewa, North Hararge, Tigray, Gonder, Wollega, Kefa and Sidamo areas of Ethiopia (Westphal, 1974; Edwards et al., 2019). It is a trailing, perennial herb; with a single branched, slender, flexuous stem around 7-15 cm long and commonly grows in habitats such as grassland, pathways, woodland, roadsides, and grassy savanna on stony ground. It propagates from conspicuous seeds which are produced in pods. The tuber (underground stem) of *E. cordifolium* is harvested from the wild for local use as a food and consumed raw as a snack food especially by children (Boke et al., 2015; Edwards et al., 2019).

Factors such as habitat degradation and loss that affect forest resources are threats to wild edible plants hence appropriate conservation thereof is of paramount importance (Lulekal et al., 2011). However, the current state of knowledge concerning the ecological distribution, seed germination requirements and nutritive values of many wild edible plants, including *E. cordifolium* is scarce. Therefore, this pilot study was aimed to understand the germination requirements and composition of some nutrients in *E. cordifolium* native and overlooked wild edible plant species.

MATERIALS AND METHODS

The study species and sample preparation

Samples of tubers and pods of *E. cordifolium* were collected from *Gara sofa* cliff which is located nearby Bishoftu town at the altitude of 2300 m a.s.l. during September 2020 (Figure 1).

The seed samples were exposed to sunlight until well dried. They were cleaned following the seed processing procedure and pure seeds were kept in plastic bags and transported to the seed germination

laboratory of the Ethiopian Biodiversity Institute (EBI) to undertake germination tests. Similarly, the dried tubers were also stored in plastic bags and transported to EBI's nutrition laboratory for nutritional composition analysis.

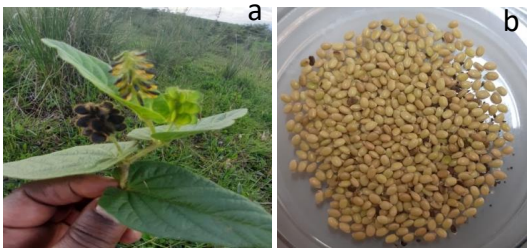

Figure 1. *E. cordifolium*, the plant (a) and its seeds (b); (photo taken by Debissa Lemessa in nearby Bishoftu town).

Germination pretreatment and nutrition analysis

The germination pretreatment was undertaken using four different methods: (1) using sand substrata and keeping in the oven at 33°C, (2) soaking in cold water for 24 hrs, (3) soaking in hot water (70°C) for 15 minutes and (4) applying mechanical scarification using scissors. For treatment methods 2 to 4, seeds were spread on moistened blotting paper in petri dishes after the seed treatments. The petri dishes containing seeds were kept in a growth chamber at room temperature (~25°C). Seed germination was monitored daily and germinated seeds were recorded for one month from October to early November 2020.

For nutrition analysis samples of tubers were chopped into small pieces to facilitate drying and were kept in an incubator at 30°C for two weeks and dried tubers were ground into powder. Data were recorded for crude fat, mineral ash and moisture contents. Each analysis was conducted in replicates. All analyses were carried out following the official methods of analysis of the Association of Official Analytical Chemists (AOAC, 2000).

RESULTS AND DISCUSSION

Germination

The germination tests showed that mechanical scarification is the most promising method when compared with other methods giving 65% of seed germination (Figure 2). This result corroborates with previous studies which stated that the seeds of *Eriosema* species may benefit from scarification before sowing (Fern, 2014). A germination rate of 70% has also been reported for seeds of other species in the genus Eriosema (SCS, 1979).

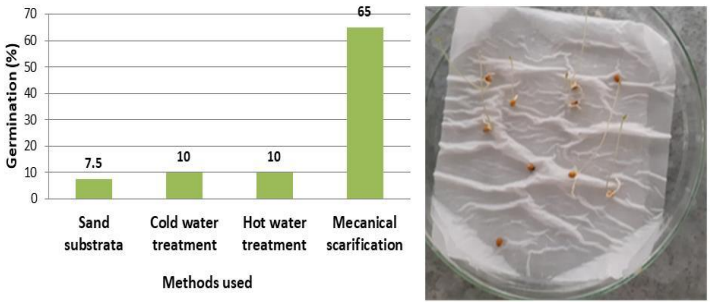

Figure 2. Germination per cent of *E. cordifolium* using different methods (left) and germination after mild scarification with scissors (right).

Nutrient composition

The result of the nutrition analysis showed that *E. cordifolium* has an average crude fat content of 0.55%, mineral ash content of 6.05% and 16.59% of moisture content (Table 1). When compared with the nutrient composition of domesticated crops with edible tubers, taro and yam (Akalu and Geletu, 2019), *E. cordifolium* showed lower crude fat content and high total ash content.

Table 1. Composition of mineral ash, crude fat and moisture in *E. cordifolium*

Replication	% Mineral ash	% Crude fat	% Moisture
1	6.09	0.56	16.79
2	6.06	0.55	16.56
3	6.01		16.42
Mean	**6.05**	**0.55**	**16.59**

According to Fern (2014), the root of *E. cordifolium* is commonly used as a vegetable in Africa. A study on the presence of chemicals that may cause health risk showed that *E. cordifolium* is free from heavy metals including cadmium, lead and copper which cause risks to health (Boke et al., 2015). These studies suggest that the species could be a potential source of food and useful minerals.

In this short communication, we have addressed seed germination requirements and composition of some nutrients in *E. cordifolium*. The results showed that seed germination was better after scarification and the species higher mineral ash content. The findings in this preliminary study could be subjected to limitations since it was carried out using samples from a single location. However, it could serve as a starting point for further research by taking multiple samples from different growing ranges to know more about the species and its potential values.

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