

Multidisciplinary Investigation on *Moringa stenpetala* (Haleko): Experiences and lessons learned through One Health-Ecohealth Approach

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Abstract

Background: *Moringa stenopetala* is a multipurpose plant in areas where it grows. This study aims to explore the health and nutritional values of *M. stenopetala*, the interaction between the socioeconomic, environmental, aspects of cultivating and commercializing the tree products through One Health-Ecohealth approach.

Methods: It is a multisectoral and interdisciplinary community-based study conducted in *M. stenopetala* consuming (Konso, Derashe, and Hammer) and non-consuming areas (Bonkey and Chench) of Southern Ethiopia. The study also comprised of experimental trial sites, field areas and various laboratories-based studies to generate scientific information and technology packages.

Results: Prevalence of vitamin-A deficiency in *M. stenopetala* consuming group was lower compared to the non-consuming group. Anterior neck mass in moringa consuming and non-consuming study sites did not reveal thyroid gland enlargement. Health facility-based prospective study on chronic care follow up for one year on voluntary participants showed that daily and weekly consumption of *M. stenopetala* reduced blood pressure and fasting blood sugar level. The mean measurements of cholesterol, low-density lipoprotein, triglyceride and systolic blood pressure had lower scores in the moringa-consuming areas. Vast integration of species diversity concerning 18 crops and 22 tree species in a piece of land was observed with a dominance of *M. stenopetala* tree. Maximum fresh leaves biomass (823g per tree) was recorded at a lower pollarding height (0.5meter). The highest fresh leaf biomass was recorded as 3110 Kg⁻¹ on 2m×2m spacing.

Conclusion: *Moringa stenopetala* has nutritional, health, agroforestry, environmental and socioeconomic benefits. Therefore, its use and conservation have to be properly exploited.

Keywords: One health- Eco health, multisectoral, *Moringa stenopetala*, interdisciplinary

Introduction

The One Health concept represents a visionary paradigm shift for health and health care by promoting interdisciplinary communications and collaborations for more expeditious public health, veterinary, biomedical and environmental research and discoveries (Kaplan 2011). It enhances the integration of animal, human, environmental health and all other related disciplines that have a much greater chance to address long-term ecological challenges for the benefit of all by demonstrating one health practice (Kaplan et al. 2009). The Eco-Health paradigm, however, takes a broader view of health and links public health to natural resource management within an ecosystem approach to human health. Eco-Health is seen as a One Health approach that optimizes interdisciplinarity

including strong participatory and community components (Barrett and Bouley 2015). One Health and Eco-Health (OHEH) are convergent in their vision and goals that health concerns must be addressed at the human-animal-plant interface within their broader natural and social environments (Figure 1). OHEH seeks to improve communication and encourage collaboration among public health professionals, physicians, veterinarians, environmental scientists, ecologists, biomedical and agricultural scientists to find multidisciplinary solutions to the challenges and mitigate the risks threatening the ecosystem to attain enhanced, expeditious and optimal health for people, domestic animals, wildlife, plants and the environment (Bunch and Waltner-Toews 2015; Roger et al. 2016).



Figure 1: Integrated One health-Ecohealth focused approach

Moringa stenopetala is locally known as “Halako” where it is endemically grown and also named “Shiferaw” where its seedlings are introduced and cultivated in other parts of Ethiopia. It is used by the indigenous community of South and Southwestern Ethiopia as food commodity, animal feedstock, medicine, edible oil, dye, water purification, hedge, soil erosion, windbreak etc. (Mekonnen and Gessesse, 1998, Abrar and Azmaxh, 2017). Numerous medicinal properties and nutritional value have been attributed and reported on *M. stenopetala*. (Toma et al. 2016; Geleta et al. 2016; Dadi et al. 2020). Despite the nutritional and medicinal values, environmental, biodiversity, agro-forestry, income source and economic significance of *M. stenopetala*, there are limited and fragmented reports on community-based study about the health and nutritional values due to consumption of *M. stenopetala*. In addition to this, the scientific information so far generated are not exhaustive besides less effort in technology development to maximize its benefits.

This interdisciplinary, multisectoral and holistic investigation on *M. stenoptala* has therefore been initiated through OHEH approach, which was envisaged to address the knowledge gap through generation of scientific information besides the production of technology packages and piece of evidence for end-users and decision-makers. The study explores the health and nutritional benefits; interaction between socioeconomics and commercialization; impact on agroforestry and environment; and other aspects of *M. stenopetala*.

Materials and Methods

The investigation on *M. stenopetala* involves a multisectoral interdisciplinary research approach and

is comprised of health and nutrition, agro-ecology and economic valuation, and socio-economic study components. The study design for the health and nutrition components is epidemiological investigation, viz., comparative community based (732 adult and 732 under five children study participants) and unmatched case-control (109 cases of hypertension and diabetes, and 227 control study participants) cross-sectional study in moringa growing/consuming (Konso, Derashe Humbo and Hammer) and moringa non-growing/non-consuming (Bonkey and Chench) selected woredas of Southern Nations, Nationalities and Peoples’ Regional State (SNNPRS). The investigation on value chain of *M. stenopetala* products was conducted in Gamo, Segen, S. Omo and Woleyta zones selected woreda.

A health facility-based prospective study was conducted for one year on 223 study participants. The study participants were diabetics, hypertensive and co-morbidity (both diabetes and hypertension) who were on chronic care follow up at Chench and Gidole hospitals located in a similar agro-ecological condition that differs only in the consumption of *M. stenopetala*. Laboratory investigation on the blood specimen collected from the study participants was carried out for vitamin-A, biochemical parameters and physical measurements, and metabolic syndrome.

Data were collected using the WHO STEPS questionnaire and a locally constructed structured questionnaire that was modified following a pretest for data collection. IBM SPSS Statistics (Version-22) (IBM Corp., 2013) was used to analyze the data.

Descriptive statistics like frequency tables, graphs, descriptive summaries, and narrative texts were used to summarize and describe the results. Biochemical

and physical parameters were also evaluated to determine the risks or potential predictors for the metabolic abnormalities or syndrome using unadjusted odds ratio (OR) and 95% confidence interval (CI). Multivariate data analysis was also performed to determine the associated factors based on $p < 0.05$ with 95% confidence level. In addition to this, various laboratory-based studies were undertaken for the development of scientific evidence and health technology products. Indicator organisms, namely, *S. aureus*, *E. coli*, *Salmonella* species, *P. aeruginosa*, *K. pneumonia* and *C. albicans* determination besides total viable aerobic viable count, total mold and yeast count were determined to ensure the microbial quality of the formulated technology products. In addition to this, sensory acceptability tests, physicochemical, efficacy and safety evaluation was also undertaken for the health technology products.

The agroecology and economic valuation component composed of the agroforestry study was undertaken in the experimental sites and field-based studies in Konso, Derashe, Arba Minch Zuria, Humbo and Hammer of SNNPRS to evaluate the impact of *M. stenopetala* trees on the environment and agroforestry potential. SAS version-9 software was used to analyze the mean value of green leaf, branch biomass and leaflet after checking the data for normality and other parametric assumption. All data on tree production in response to different planting spacing were subjected to a generalized linear model test with a one-way analysis of variance (ANOVA). The economic

valuation involves community-based study to collect pertinent information from the community members besides mapping moringa growing sites. The socio-economic study component comprised moringa value chain for livelihoods of smallholder farmers and perception studies in the community members.

Scientific and ethical approval was provided by the Institutional Review Board of Ethiopian Public Health Institute (EPHI-IRB). Data were collected anonymously, and confidentiality was maintained. Letter of support was obtained from Health and Agricultural Bureau of SNNPRS to facilitate the study. Informed consent was obtained from adult study participants and proxy consent from guardians for children less than five years, and assent was obtained from children between 16 and 18 years before administering the questionnaire and collecting biological specimen.

Results

Health and Nutrition

Vitamin-A and hemoglobin level in adult and under-five children in moringa consuming and non-consuming areas: The result revealed that prevalence of vitamin A deficiency in *M. stenopetala* consuming and non-consuming adults were 10.18% with 95 % CI (5.40, 11.40) and 19.85% with 95% CI (13.2, 23.0), respectively. The prevalence of vitamin A deficiency among under-five children in the moringa consuming group was 30.5%, whereas in the non-consuming areas, it was 42.9% (Figure 2).

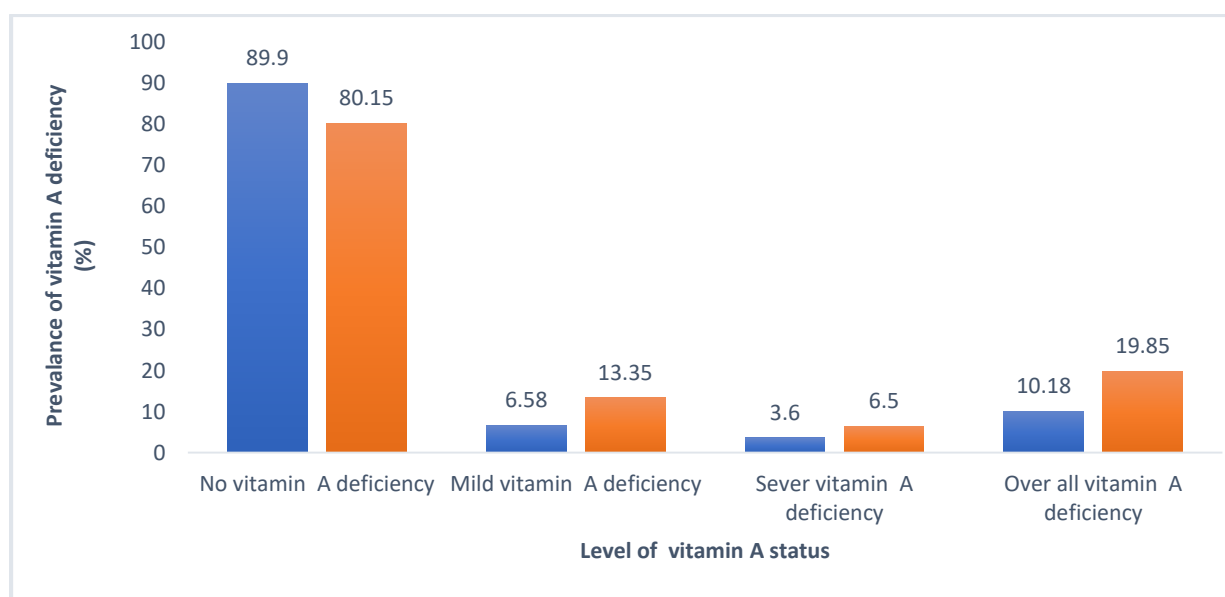


Figure 2: Prevalence of Vitamin A deficiency in the studied villages of moringa consuming and non-consuming areas

The mean serum retinol level in moringa consuming areas was 1.62 ± 0.77 with 95% CI (1.52, 1.70) and was significantly higher ($p < 0.05$) than in non-consuming areas, which was 1.24 ± 0.65 with 95% CI (1.16, 1.32). Dietary consumption of *M. stenopetala* based diet as food for the whole seven days gave rise to a high mean serum retinol level of 1.88 (1.62, 2.15) compared to non-consumption of moringa 1.26 (1.18, 1.34). The mean serum retinol level in under-five children in the moringa consuming areas was $0.98 \pm (0.89, 1.05)$, whereas in the non-consuming areas, it was 0.86 (0.76, 0.95). The mean with standard deviation (SD) hemoglobin status of the children was 12.16 ± 3.02 . Anemia prevalence was significantly higher ($p < 0.05$) among the age group of 6–11 months compared to the age group of 24 to 35 months ($P = 0.024$), 36 to 47 months ($P = 0.028$), and 48 to 60 months ($P = 0.002$). There was no significant difference ($p > 0.05$) in the mean hemoglobin and prevalence of anemia among children with different wealth quintiles.

Effect of *M. stenopetala* consumption on biochemical and physical parameters: The mean values for biochemical parameters for moringa consuming and non-consuming study participants were $85.6 \text{ mg/dl} \pm 17.5$ versus $74.2 \text{ mg/dl} \pm 18.3$ for fasting blood sugar (FBS), $162.5 \text{ mg/dl} \pm 39.7$ versus $146.8 \text{ mg/dl} \pm 38.7$ for total cholesterol (T-cholesterol), $45.7 \text{ mg/dl} \pm 16.9$ versus $35.6 \text{ mg/dl} \pm 10.1$ for high density lipoprotein cholesterol (HDL-Cholesterol), $85.7 \text{ mg/dl} \pm 32.0$ versus $80.5 \text{ mg/dl} \pm 30.5$ for low density lipoprotein cholesterol (LDL-Cholesterol), $128.6 \text{ mg/dl} \pm 68.1$ versus $115.5 \text{ mg/dl} \pm 50$ for Triglycerides, respectively.

The result also revealed that there was no significant difference ($p > 0.05$) in physical measurement values. The chi-square test revealed that there was no significant difference ($p > 0.05$) for the unconditional prevalence of raised blood pressure, raised fasting blood sugar and serum level between moringa consuming and non-consuming areas. Moreover, the majority of the study participants in both study sites were not at risk of metabolic syndrome for cardiovascular disease (CVD) (Chi square and p-test 3.514, 0.12). Both bivariate and multivariate logistic regression analyses for the overall biochemical and physical measurement values of the study participants did not show significant difference ($p > 0.05$) between the study sites (Table 1). The mean value of waist circumference was 85.5 cm and 81.6 cm; average systolic BP values were 124.9 mmHg and 120.1 mmHg; average diastolic BP values were 83.8 mmHg and 79.6 mmHg; and body mass index values were 22.9 and 22.3 Kg/m² irrespective of sex difference for moringa consuming and non-consuming areas, respectively.

Effect of consumption of *M. stenopetala* on thyroid gland function: A total of 1459 participants were included in moringa consuming and non-consuming areas to resolve controversial reports about the long period consumption of *M. stenopetala* and the health risk as an exacerbating factor for goiter. The mean age of the study participants was 30.7 ± 3.9 years. Half of the study participants were children between 1 to 5 years. Test for the presence of iodine in the household salt (iodized salt) used for food preparation in the study areas indicated the presence of sufficient iodine ($> 15 \text{ ppm}$) in 47.6% of moringa consuming and 58.9% of non-consuming households.

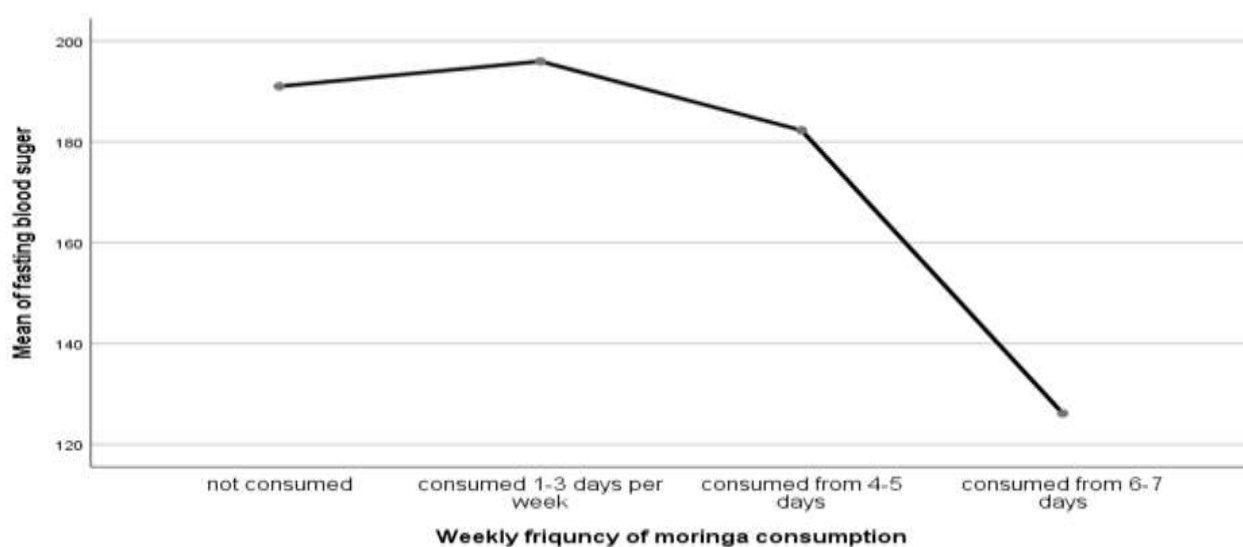
Examination of the household members for anterior neck mass or enlarged thyroid gland did not reveal the presence of thyroid gland enlargement in the majority of households in moringa consuming and non-consuming areas (95.4% and 98.6%, respectively). The mean thyroid-stimulating hormone (TSH) levels in adults from moringa consuming and non-consuming areas were 1.47 and 1.41 mIU/ml, respectively; while those in children were 2.5 and 3.36 mIU/ml, respectively. Similarly, the mean total Tetraiodothyronine (T₄) and Triiodothyronine (T₃) levels were within the normal range of interval of the test kits. Though the mean value of TSH seems to decrease among adults and to increase among children in moringa non-consuming areas compared to those in the consuming areas, the differences were not statistically significant ($p > 0.05$).

Health facilities-based prospective follow up studies: The result showed that frequent daily and weekly consumption of *M. stenopetala* had a reducing effect on blood pressure (both diastolic and systolic) and fasting blood sugar level. In the first six months, the mean cholesterol, high-density lipoprotein (HDL), systolic blood pressure, diastolic blood pressure and fasting blood sugar had significant difference ($p < 0.05$) in moringa consuming and non-consuming areas. Except fasting blood sugar level, the mean was lower in the moringa consuming areas compared to the non-consuming areas (Figure 3). The mean cholesterol, low-density lipoprotein (LDL), triglyceride (TG) and systolic blood pressure had lower values in the moringa consuming areas compared to the non-moringa consuming areas in the second-round laboratory tests.

Assessment of undernutrition in *M. stenopetala* consuming vs non-consuming areas: The nutritional contribution of *M. stenopetala* in under-five children in selected rural and urban villages of moringa consuming and non-consuming areas was assessed by determining the status of stunting based on WHO Z-score.

Table 1: Prevalence of metabolic syndrome among moringa consuming and non-consuming adult populations in selected rural and urban kebeles of the study sites (N=731)

Variable characteristics	Study sites					
	Moringa growing areas Yes (#, %)	Non-moringa growing areas No (#, %)	χ^2 Test, p-value	Moringa use as food source or medicine		χ^2 Test, p-value
				Yes (#, %)	No (#, %)	
Unconditional prevalence of raised BP	60 (16.1)	56 (15.6)	6.597, 0.19	31 (7.9)	53 (15.5)	3.28, 0.27
Unconditional prevalence of raised blood sugar	8 (2.8)	8 (3)	5.07, 0.14	10 (3.2)	8 (3.1)	2.42, 0.12
Prevalence of fasting blood sugar						
Normal (<100 mg/dl)	288 (96)	258 (95.6)		303 (97.7)	247 (95.4)	
Impaired fasting glucose (100-125 mg/dl)	8 (3)	9 (3.3)	5.23, 0.13	5 (1.6)	9 (3.5)	3.9, 0.11
Raised blood sugar (≥ 126 mg/dl)	3 (1)	3 (1.1)		2 (0.6)	3 (1.1)	
Prevalence of metabolic syndrome	35 (9.9)	37 (10.1)	10.73, 0.11	55 (8.6)	45 (13.1)	3.51, 0.12

**Figure 3: Moringa frequency of dietary feeding habit Vs mean FBS during follow up periods (n = 336)**

Height-for-age (HAZ) is age and sex-normalized measure of child height < 2yrs old relative to the median age of the reference population. It is expressed as linear growth retardation and cumulative growth deficits and indicates whether it results from chronic malnutrition. The overall mean HAZ was -1.53 ± 2.12 in all study participants in both moringa consuming and non-consuming areas. The mean (Standard deviation) of Z-score of HAZ is -1.53 ± 1.91 in moringa consuming areas and -1.65 ± 2.1 in non-moringa consuming areas. The prevalence of stunting in the moringa consuming areas was 19% with 95% CI (17.00, 21.00) and non-consuming areas 28.80% with 95% CI (26.4, 31.2). There was significant difference ($p < 0.05$) in stunting status being relatively higher in moringa non-consuming areas compared to consuming areas ($p = 0.03$). Weight-for-age (WAZ) is

a good index to assess the long and short-term contribution of moringa consumption. The overall median Z-score of underweight was -0.1943 ± 2.12 for all study participants in both moringa consuming and non-consuming areas. The weight-for-height (WHZ) index measures body mass concerning body height or length and describes the current nutritional status of children (Table 2). The mean Z-score of WHZ was 0.95 ± 3.13 in moringa consuming areas and 1.12 ± 3.088 in non-consuming areas. The prevalence of wasting or weight-for-height in the moringa consuming areas was 4.7% with 95% CI (3.6, 5.8) and non-consuming areas 9.60% with 95% CI (8.08, 11.28). There was significant difference in wasting status being relatively higher in moringa non-consuming areas compared to consuming areas ($p < 0.001$) (Table 2).

Table 2: Anthropometric measurements of under five years children among the comparative study population in study sites (N=732)

Nutritional index	Category nutritional status	Study Areas	
		Moringa consuming areas (%)	Moringa non-consuming areas (%)
Stunting (Ht for age) (HAZ)	Stunting	19	28.8
	Normal	81	71.2
Wasting (Wt for Ht) (WHZ)	Wasting	4.7	9.77
	Normal	95.3	90.1
Underweight (Wt for age) (WAZ)	Under weight	12.2	13.7
	Normal	87.8	86.3

Cut off points: Normal nutritional status was -2 or more for HAZ, WHZ and WAZ score. Moderate stunting (HAZ-score), wasting (WHZ-score) and underweight (WAZ-score) ranges from -3 to -2; severe stunting (HAZ-score), wasting (WHZ-score) and underweight (WAZ-score) are less than -3; and overweight (WHZ-score) is ≥ 2

Weight-for-age (WAZ) is a composite index of height-for-age and weight-for-height accounts for both acute and chronic undernutrition. It is a good index to assess the long and short-term contribution of *M. stenopetala* based diet consumption on child growth.

Health technology products: The nutrient composition of the traditional moringa foods (*Kurkufa* and *Fosese*) prepared by the indigenous community collected from the households of Konso and Derashe, the selected *M. stenopetala* consuming study sites were assessed for their nutritional value, anti-nutrient factors and other parameters in the laboratory.

The result showed variation in total proximate composition, crude fiber, fat and moisture content between Derashe and Konso areas where *M. stenopetala* dominantly grows and is consumed as a staple food by the community. The generated data were utilized for the formulation of *M. stenopetala* leaves to powder and flour blend supplementation as a means to produce a complementary food for infants and young children to fill the energy and nutrient gap of mother's milk.

Fourteen formulation recipes were made from unprocessed and processed grains supplemented with 5% and 10% of *M. stenopetala* powder. Among the 14 formulations, two preferred ratios of formulations (formulation 10 and 12) were selected based on nutritional value (protein and energy) and sensory acceptability while two unfortified formulations were used as control.

Moringa stenopetala leaves have undesirable tastes and flavour when consumed as vegetables, soup or as

herbal tea infusion for medicinal purposes unless salt or sugar is added to make it appealing and improve the taste. Fresh leaves of *M. stenopetala* also easily deteriorate during harvesting, processing and storage. As a means to counteract the undesirable tastes, flavor and deterioration of *M. stenopetala*, and enhance its medicinal value, tea granules were formulated by admixing pulverized and sieved leaves of *M. stenopetala* with three herbal adjuvants, i.e., *Thymus serralatus*, *Cymbopogon citratus* and *Mentha spicata* separately. The formulated tea granules improved palatability and flavor besides producing a stable medicinal product preventing microbial degradation and decomposition of the chemical constituents as determined by microbial quality control test and sensory evaluation. The tea infusion of the tea granules of *M. stenopetala* blended with herbal adjuvants induced a plausible increase in urine volume and urinary electrolytes concentration leading to reduced elevated blood pressure. The tea infusion also decreased elevated blood sugar levels. The tea infusion also showed good physicochemical, microbial quality and safety properties, as well as sensory acceptability. Among the three tea granule formulations, *M. stenopetala* and *M. spicata* blended tea formulation showed better safety, efficacy and physicochemical properties compared to the other blends.

Agroforestry

The experimental and field based agroforestry studies were conducted to determine the agronomical factors and parameters pertaining to *M. stenopetala* in experimental sites and at field setup.

Growth performance of *M. stenopetala* and its effect on carbon stock sequestration: Studies on the effect of altitude on growth performance and carbon stock sequestration potential of *M. stenopetala* that was conducted at three villages of farmer's field revealed that the height and diameter (dbh) of *M. stenopetala* was significantly higher at lower altitude compared to mid and high altitude (Table 3).

Table 3: Growth performance and carbon sequestration potential of *M. stenopetala* at different altitudes under different plant age groups

Age group (5-10 months)								
Altitudinal range	Ht. (m)	Dm (m)	AGB (Kg)	BGB (Kg)	TB (Kg)	TCC (Kg)	CO ₂ fixed/tree	CO ₂ fixed/tree/year (Kg)
1200-1300	6.44	.22	35.02	6.98	42.00	21.00	77.04	10.27
1600-1700	4.68	.15	11.09	2.22	13.31	06.66	24.40	03.25
1900-2000	5.09	.12	8.65	1.73	10.38	05.19	19.02	02.54
Mean	5.40	0.16	18.25	3.64	21.90	10.95	40.15	5.35
C _D (.05)	1.24	.05	12.84	2.58	15.42	7.71	28.33	3.78
Cov.	17.90	21.43	54.70	55.08	54.76	54.76	54.85	54.85
Age group (10-15 months)								
Altitudinal range	Ht. (m)	Dm (m)	AGB (Kg)	BGB (K)	TB (Kg)	Total carbon contents (Kg)	CO ₂ fixed/tree (Kg)	CO ₂ fixed/tree/year (Kg)
1200-1300	6.77	0.34	81.70	16.34	98.04	49.02	179.72	14.38
1600-1700	6.87	0.22	35.59	7.12	42.71	21.35	78.22	6.26
1900-2000	6.08	0.18	21.66	4.33	25.99	13.00	47.65	3.81
Mean	6.57	0.25	46.32	9.26	55.58	27.79	101.86	8.15
C _D (.05)	NS	.05	24.59	4.32	25.91	12.95	47.52	3.80
Cov.	12.46	14.77	36.24	36.24	36.24	36.24	36.27	36.24
Age group (15-20 months)								
1200-1300	7.54	0.42	143.18	28.64	171.82	85.91	314.97	18.00
1600-1700	7.47	0.25	50.52	10.10	60.63	30.31	111.14	6.35
1900-2000	7.01	0.22	37.68	7.54	5.22	22.62	82.94	4.74
Mean	7.34	0.30	77.13	15.43	92.56	46.28	169.68	9.70
C _D (.05)	NS	0.06	54.64	10.93	65.57	32.77	120.15	6.87
Cov.	10.99	15.22	55.07	55.07	55.07	55.05	55.05	55.05

- Density of *Moringa* = 262 Kg/m³ [used from Global wood density database]
- Ht = Height, Dm = Diameter, AGB = Above ground Biomass, BGB = Below ground biomass, TB = Total Biomass, TCC = Total carbon contents

However, no significant variations ($p > 0.05$) in growth parameters were found between low and mid-altitude. *Moringa stenopetala* tree sequestered carbon stock on an average of 10.95 Kg, 27.79 Kg and 85.91 Kg for 5-10, 10-15 and 15-20 age class of tree, respectively and thus trap CO₂ of 40.15 Kg, 101.86 Kg and 314.97 Kg for the same. The annual sequestration of CO₂ was found maximum for class 15-20 (18 Kg) followed by 10-15 class (8.15 Kg) and lowest for 5-10 class (5.35 Kg). Similarly, CO₂ fixed per tree and CO₂ fixed /tree/year was found maximum at lower altitude (77.04 Kg and 10.27 Kg, respectively).

No significant variation for Carbon and CO₂ was observed among lower and mid-altitude ($p > 0.05$). No significant variation was also observed for height among these three altitudes for these age classes. The height of these trees ranged from 6.08 m to 6.87 m. However, in the case of diameter, the variation was found significant for lower altitude with the highest diameter (0.34 m) followed by middle (0.18) and high (0.22) where middle and higher elevation did not show significant variation at 5% level of confidence (Table 3).

Growth performance and carbon sequestration potential of *M. stenopetala* along an altitudinal gradient: The study was conducted in a farmer's field

with the aim of determining the effect of altitude on growth performance and Carbon stock sequestration potential of *M. stenopetala* at three locations with altitudinal ranges of low, middle and high, and three different age classes of the trees ranging 5 to 20 years. The result indicated that the growth performance and carbon sequestration of *M. stenopetala* was significantly higher ($p < 0.05$) at a lower altitude as compared to mid and high altitudes. The growth pattern was the same for all three-age classes. *Moringa stenopetala* tree can on average sequester carbon stock of 10.96 kg, 27.87Kg and 42.31 Kg for 6-10, 11-15 and 16-20 age classes, respectively and thus trap CO₂ of 40.17 Kg, 102.20 Kg and 155.11 Kg for the same. The annual sequestration of CO₂ was found maximum for class 16-20 (8.62 Kg) followed by 11-15 class (7.86 Kg) and lowest for 6-10 class (5.02 Kg).

Effect of plant spacing on green leaf production and branch biomass of *M. stenopetala*: The study was conducted to determine the effect of optimum plant spacing for improved growth on leaf production and branch biomass after 18 months starting from planting date and indicated that germination rate and seedling growth of *M. stenopetala* was higher compared to any other tree species e.g., *Moringa oleifera*, *Terminalia brownie* and *Cordia africana*.

Moringa stenopetala seedling reached an average of 1.3m height in four months and bears 24-29 branches. The branch number indicates that when it was planted for leaf production, its leaves could be harvested in three to four months. There were no spacing effects on growth of the tree crown spread (CS), collar diameter (CD), branch number (BN) and height (H) at $p=0.05$ during the initial stage since the moisture and nutrients are sufficient for the growth of the seedling of *M. stenopetala*. Furthermore, competition for light was low at this stage due to less canopy coverage and short branches of the tree.

Spacing had a significant effect on CS, diameter at breast height (DBH) and height at $p=0.05$ when the age of the tree was increasing. Distance between two *M. stenopetala* trees had a significant effect on leaf

production, leaflet and branch biomass at 18 months of age ($p<0.05$). The 2m×2m spacing recorded significantly higher diameter at breast height (DBH) (3.64cm) than 0.5m×0.5m (1.78cm), 1m×1m (2.63cm) and 1m×1.5m (2.35cm) spacing. The wider spacing (3m×3m) recorded the highest branch number (24.72) followed by 2m×2.5m (16.38) and 2m×2m (15.10). The wider spacing produced higher root collar diameter (RCD) per plant and this was significantly different ($P<0.05$) than plants of the closer spacing throughout the study period. Treatment spacing 3m×3m, 2m×2.5m and 2m×2m was significantly higher (1640.1gm, 1222gm and 1270gm per tree, respectively) than the remaining three closer spacings. The biomass of the fresh leaf increased as the age of the tree and spacing increased (Figure 4).

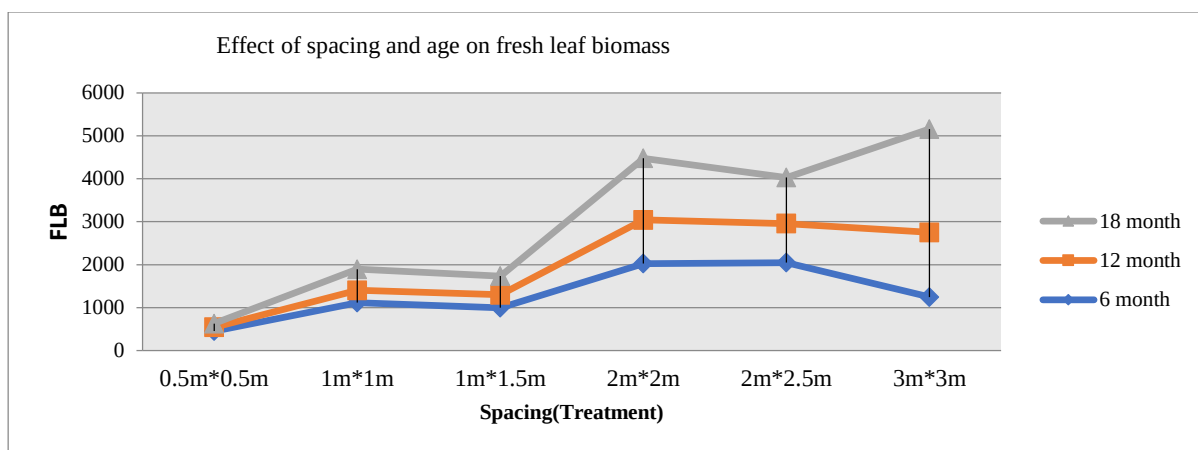


Figure 4: Effect of spacing and age on fresh leaf biomass (FLB)

Effect of plant density on early growth and carbon stock potential of *M. stenopetala*: The study was intended to determine the effect of plant spacing on growth performance and biomass carbon stock accumulation of *M. stenopetala*. The results revealed that both height and dbh of *M. stenopetala* were affected by different densities during the quarterly interval time of measurement with the exception of the first quarter when there was no effect of density on height of the plant. The mean height of the populations increased with an increase in population density. The height inequalities of the crowded populations are less and increasing during stand development, whereas uncrowded population shows the reverse phenomenon.

Moringa stenopetala has the potential to produce an average of about 9.14 Kg of carbon/plant for which it traps about 33.48 Kg of CO₂ and produce 49.92 T per ha, 183.04 T per/ha of carbon and CO₂ respectively.

At the age of 1.5 yrs., it can produce annual carbon content of 5.48 Kg by sequestering 20.09 Kg of CO₂. The result also indicated that height inequalities of uncrowded populations decreased during stand growth, whereas the height inequalities of the crowded population decreased first and then increased during stand development. It was observed that diameter growth decreases with an increase in plant density right from the beginning of the first quarter to the end of the 5th quarter. Nevertheless, the decrease in diameter is more pronounced after the third quarter (Table 4).

During the first two quarters, there was no significant variation for carbon contents among T1 (10,000 plants per ha) to T5 (5000 plants per ha). However, there was significant increase in carbon contents for a wider density of T6 (4000 plants) to T8 (3000 plants). At the end of the evaluation period, i.e., on the 5th quarter (20 months) maximum Carbon per plant (11.38 Kg) and

CO₂ per plant (41.71 Kg) was recorded for T8 (3000 plants per ha). It was observed that *M. stenopetala* has the potential to produce average carbon in the range of

0.123 Kg to 9.14 Kg from the first quarter. *Moringa stenopetala* growth can sequester CO₂ in the range of 0.45 Kg to 33.48 Kg on an average basis (Table 4).

Table 4: Height and diameter of *M. stenopetala* recorded at different intervals

Treatment	Average Plant height (m)					Average diameter (cm)				
	1 st Qut.	2 nd qut.	3 rd qut.	4 th qut.	5 th qut.	1 st qut.	2 nd qut.	3 rd qut.	4 th qut.	5 th qut.
T1	1.33	3.11	4.08	5.42	6.29	3.65	6.47	8.17	11.82	12.78
T2	1.26	3.08	4.37	5.36	6.08	3.51	6.20	9.78	12.56	14.62
T3	1.28	3.03	4.27	5.43	6.37	3.44	6.55	10.85	13.13	15.44
T4	1.25	2.99	4.41	5.58	6.24	3.69	6.84	11.86	13.01	15.57
T5	1.27	2.69	3.79	5.10	5.66	3.75	6.16	11.47	13.48	16.38
T6	1.27	2.66	3.78	5.48	5.74	4.49	6.24	11.19	13.54	15.93
T7	1.30	2.77	3.63	4.85	5.64	4.54	6.82	11.86	14.05	16.39
T8	1.24	2.83	3.84	5.24	5.81	3.86	6.92	13.50	15.09	17.65
Mean	1.27	2.90	4.02	5.31	5.98	3.87	6.52	11.09	13.34	15.60
F value	0.70	7.88	8.04	5.23	7.50	17.84	3.42	66.87	15.88	26.04
P value	0.67	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.01	<0.0001	<0.0001	<0.0001

Qut =quarter

Contribution of Moringa trees to production of alley maize in Arba Minch district: Generation of the experimental evidence on the role of moringa trees for the production of alley maize has paramount importance for improving the traditional agroforestry practices by framers to enhance increased crop output and moringa leaf biomass. The study evaluated the growth and leaf yield of two moringa tree species (*Moringa stenopetala* and *Moringa oleifera*), and their impact on the grain yield of intercropped alley maize in experimental plots. The analyses of variance on studied traits in maize revealed that both *M. stenopetala* and *M. oleifera* showed suppression of maize yield and yield components. Maize plants in control plots (away from trees) revealed significantly higher ($p < 0.05$) grain yield, biomass weight, cob number and cob length at both cropping seasons consistently. In the case of *M. stenopetala*, maize grain yield reduction ranged from 16% in the first cropping (2018) up to 23 % in the second (2019). The reduction of maize grain yields by *M. oleifera* trees was more drastic than in the plots with *M. stenopetala*, ranging from 32 % reduction in the first cropping up to 48% in the second cropping season. The economic analysis of the treatments was assessed in terms of Benefit-Cost Ratio (BCR). Accordingly, the analyses of returns to maize mono-cropping revealed lower BCR (2.36) than agro-forestry treatments. The highest BCR was recorded with treatment that integrates *M. stenopetala* with maize (5.64) followed by *M. oleifera* with maize (5.19).

Both tree species (*M. stenopetala* and *M. oleifera*) showed suppression of maize growth and grain yield but were compensated by outputs from tree products such as leaf and wood biomass yield. *M. oleifera* showed significantly higher ($p < 0.05$) growth

performance and leaf biomass than *M. stenopetala* and hence more competitive with intercropped maize. The overall yield of maize and moringa fresh leaf obtained from *M. stenopetala* treatment revealed a better product than the other three treatments. The study indicated that moringa-maize intercropping systems are more financially attractive than maize mono-cropping

Effect of pollarding on leaf biomass of *M. oleifera*

This study was conducted to determine whether different cutting/pollarding heights affect the yield and growth of the four pollarding treatments/cutting heights (0.5m, 1.0m, 1.5m and 2.0m) and one control (un-pollarded) were imposed after 12 months of planting. The result showed a maximum number of shoots per plant on un-pollarded treatment (control). Cutting height significantly affected fresh and dry biomass of leaf ($P < 0.05$). Maximum fresh *M. oleifera* leaf biomass (823 g/tree) was recorded at a lower pollarding height (0.5 meters) followed by 1.5 meters (729 g/tree). The lowest fresh leaf biomass was recorded on un-pollarded treatment (268 g/tree). Maximum and minimum dry leaf biomass was also obtained at 0.5 meters cutting height (222 g/tree) and control (73 g/tree), respectively. Cutting height affected shoot number and height significantly ($P < 0.05$).

Moringa based agri-silviculture system for agrobiodiversity conservation in the Konso and Derashe districts:

This study was undertaken to determine the composition and diversity of the trees, shrubs, and crops and their frequencies in *M. stenopetala* based agroforestry practices for agrobiodiversity conservation in Konso and Derashe districts based on the abundance of *M. stenopetala* in the farmland. The study revealed that in the *M.*

stenopetala based agri-silvicultural system of the study areas, 22 woody species belonging to 17 families were identified with dominance of *M. stenopetala* compared with other farms of non-moringa based agri-silvicultural system. Among these, 19 were from Fasha, 13 from Gamole and 13 from Holte kebeles of Konso district. Eight woody species were common for the three kebeles. Rutaceae, which was represented by 3 species was the most dominant family (Figure 5).

Out of the total 19 woody species found in Fasha, the dominantly observed species were *Moringa*

stenopetala (15.38%) followed by *Coffea arabica* (13.46%), *Juniperus procera* and *Terminalia brownii* with the same frequency (11.54, each) while 10 species had the lowest frequency (1.92%) (Figure 5). Similarly, out of the total 13 woody species found in Gamole, the dominantly observed species were *M. stenopetala* (18.52%) followed by *Terminalia brownii*, *Juniperus procera*, *Mangifera indica* with the same frequency (12.96%) while 4 species had the lowest frequency (Figure 6). Farmers integrate different crops with *M. stenopetala* and other woody species.

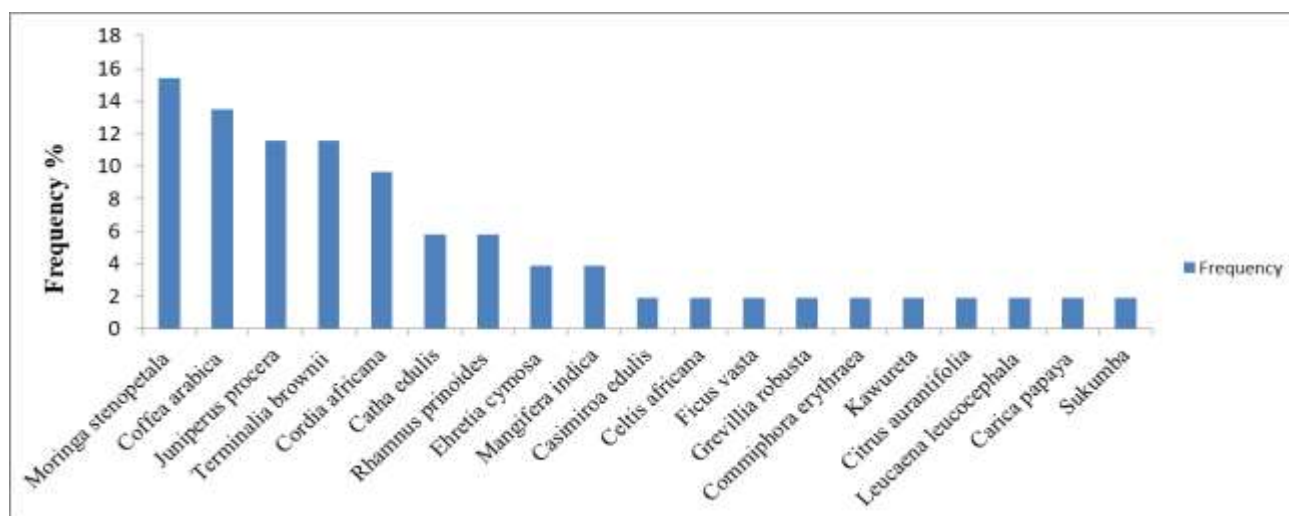


Figure 5: Frequency distribution of woody species in *M. stenopetala* based agroforestry system in Fasha, Konso

Accordingly, 18 crop species were identified growing in the agri-silviculture system in the study areas. Fabaceae, represented by 4 crops, is the dominant family followed by Poaceae (represented by three species); Asteraceae, Cucurbitaceae and Solanaceae each represented by two species; and the other families by one crop species each.

Available phosphorus (Av. P) of the study areas ranged from 25.38 to 43.86 falling very high rating. Available phosphorus was revealed similar trend for all different age groups and different distances from moringa tree trunks except 25 years old moringa tree at 3m distance from the trunk. Av. P showed a decreasing trend for 5 and 10 years old moringa trees when moving from canopy to outside open area. There was a higher value of total cation exchange capacity (CEC) under the canopy of the tree than in the adjacent open fields. It decreased significantly ($p < 0.05$) with increasing distance from the tree trunk (Table 5).

The results of Pearson correlation analysis showed that certain attributes of soil showed significant relationships with each other, whereas others did not show any significant form of relationships among

themselves. Soil reaction (pH) was significantly and positively correlated with electrical conductivity (EC) ($r = 0.830^{**}$) and Ca^{++} ($r = 0.727^{**}$). Similarly, pH was also highly significantly and positively correlated with base saturation (BS) ($r = 0.526^{**}$) and C: N ($r = 0.439^{**}$).

Ecological and economic valuation: Total economic value (TEV) of an environmental resource (ecosystem) consists of its use-value (UV) and non-use value (NUV). Attempts have been made in this study to estimate TEV of the bioresources of *M. stenopetala* tree, which would help to rehabilitate the ever-diminishing forest resources in drier areas. The study used combined environmental goods and services valuation techniques, which are contingent valuation and hedonic pricing methods to estimate willingness to pay for the value of *M. stenopetala*. Out of 220 study participants, 98.2 % were farmers and the remaining 1.8% were merchants. The mean average intercropped size of land with *M. stenopetala* in the study area was 1.10 hectares. The study participants indicated that they were consuming *M. stenopetala* leaves daily as a vegetable.

Table 5: Influence of *M. stenopetala* tree on selected soil chemical properties

Age (Years)	Distance (m)	Soil Chemical Properties Fasha Site													
		PH (H ₂ O)	EC (ds/m)	TN (%)	OC (%)	OM (%)	C/N	Av. P (PPM)	P ₂ O ₅	Na	K	Ca	Mg	CEC	BS (%)
5	2	6.6	0.137	0.14	1.55	2.68	11	40.26	92.20	0.14	1.68	31.23	8.92	50.6	83
	4	6.5	0.134	0.14	1.53	2.64	11	40.58	92.93	0.17	1.55	31.44	8.89	52.8	80
	6	6.5	0.147	0.16	1.76	3.04	11	40.18	92.01	0.22	1.72	30.55	8.70	44.6	92
	8	6.4	0.126	0.14	1.55	2.67	11	34.98	80.10	0.21	1.44	29.81	8.65	49.1	82
10	2	6.4	0.138	0.15	1.61	2.78	11	47.40	108.55	0.18	1.55	30.50	8.47	45.8	89
	4	6.5	0.188	0.12	1.44	2.48	12	40.18	92.01	0.25	1.63	40.10	8.22	74.0	68
	6	6.4	0.134	0.12	1.43	2.46	12	28.70	65.72	0.19	1.30	31.23	8.15	49.7	82
	8	6.4	0.150	0.15	1.61	2.77	11	37.68	86.29	0.28	1.93	33.74	9.20	47.9	94
25	2	6.4	0.156	0.16	1.77	3.06	11	30.02	68.75	0.26	1.43	34.60	10.24	55.9	83
	4	6.4	0.136	0.16	1.71	2.94	11	16.98	38.88	0.24	0.93	34.71	10.19	55.8	83
	6	6.4	0.198	0.15	1.79	3.09	12	25.38	58.12	0.23	1.57	38.11	10.55	51.9	96
	8	6.4	0.156	0.16	1.90	3.28	12	43.86	100.44	0.23	1.65	40.19	10.53	54.9	98
Gamole Site															
5	2	6.4	0.123	0.12	1.27	2.19	11	18.36	42.04	0.24	0.81	34.47	11.38	54.1	87
	4	6.5	0.203	0.18	1.96	3.38	11	49.56	113.49	0.21	1.77	37.59	11.65	54.0	95
	6	6.5	0.136	0.11	1.13	1.94	10	13.04	29.86	0.26	0.67	42.94	11.94	58.3	96
	8	6.5	0.133	0.07	0.76	1.32	11	13.16	30.14	0.18	0.69	39.79	10.88	55.7	93
10	2	6.4	0.158	0.14	1.58	2.72	11	16.02	36.69	0.28	0.96	37.55	11.75	72.9	69
	4	6.4	0.155	0.16	1.85	3.19	12	25.86	59.22	0.16	1.03	36.83	11.69	59.8	83
	6	6.4	0.172	0.17	1.90	3.28	11	33.20	76.03	0.17	1.66	34.68	11.69	56.6	85
	8	6.4	0.172	0.12	1.23	2.12	10	13.50	30.92	0.14	0.66	34.02	11.61	72.0	65
25	2	6.9	0.183	0.18	2.06	3.55	11	16.68	38.20	0.17	1.03	40.35	11.84	76.6	70
	4	6.6	0.152	0.15	1.61	2.77	11	7.86	18.00	0.10	0.63	36.36	11.05	50.8	95
	6	6.6	0.136	0.14	1.54	2.65	11	9.14	20.93	0.12	0.51	36.36	11.07	54.2	89
	8	6.5	0.133	0.14	1.46	2.51	10	8.54	19.56	0.09	0.55	36.87	11.09	54.3	89
Holte Site															
5	2	7.0	0.260	0.08	0.96	1.65	12	5.56	12.73	0.23	1.43	43.02	11.81	56.2	101
	4	7.0	0.226	0.08	0.88	1.52	11	3.28	7.51	0.20	0.97	42.94	11.83	56.3	99
	6	7.1	0.222	0.06	0.70	1.21	12	2.48	5.68	0.08	0.58	44.22	10.57	56.6	98
	8	7.1	0.218	0.05	0.62	1.08	12	2.92	6.69	0.05	0.43	44.66	10.78	56.3	99
10	2	7.2	0.262	0.08	0.84	1.44	10	2.36	5.40	0.07	1.79	43.46	9.95	58.0	95
	4	7.2	0.212	0.07	0.76	1.30	11	1.84	4.21	0.06	0.57	42.82	9.47	52.2	101
	6	7.3	0.214	0.06	0.64	1.11	11	2.44	5.59	0.10	0.71	42.54	9.55	57.7	92
	8	7.3	0.193	0.04	0.51	0.88	13	2.62	6.00	0.05	0.55	41.42	9.13	54.4	94
25	2	7.2	0.256	0.04	0.55	0.95	14	7.46	17.08	0.07	0.74	42.58	11.11	56.6	96
	4	7.2	0.260	0.07	0.81	1.40	12	4.86	11.13	0.09	0.63	41.82	10.84	56.0	95
	6	7.2	0.228	0.06	0.72	1.25	12	3.30	7.56	0.07	0.70	43.58	11.54	56.1	100
	8	7.3	0.269	0.06	0.75	1.29	13	7.40	16.95	0.12	0.74	37.95	11.55	49.7	101

Note: EC = Electrical conductivity, OC = Organic carbon, OM = Organic Matter, TN= Total nitrogen, C/N =Carbon/Nitrogen, Av. P = Available phosphorus cmol =Exchangeable cation composition, CEC = Total cation exchange capacity, BS = Base saturation

The mean consumption of the leaves per week per household was 5.56 bundles. One hundred forty-five (65.9 %) of the study participants sold *M. stenopetala* leaves at the local market and earn an average of 91Ethiopian Birr per week, which is 4566 for 50 weeks per year. Moreover, *M. stenopetala* leaf was more preferable by the local communities for food and traditional medicine at household level than selling in the market. TEV of *M. stenopetala* per year per person was found to be 12,263Ethiopian Birr per year per household (HH). Regarding willingness to pay (WTP)

for *M. stenopetala* future direct and indirect use value prospect was the maximum willingness to pay, which is accounted to be 9,000 Ethiopian Birr per HH per year. The WTP results of Derashe area people's zone study participants were the highest with annual mean of 758 Ethiopian Birr for the service obtained from *M. stenopetala*, it was followed by Gamo and Gofa zones that were 690 Ethiopian Birr (Table 6). The survey showed yearly average WTP per individual tree of the study participants to the service obtained from *M. stenopetala* was 2350 Ethiopian Birr with a maximum

WTP value of 689 Ethiopian Birr per year and the minimum value of willing to pay. The plant growth potential suitability analysis result indicated many agro-ecologies of the country were found to be ideal sites for the growth and adaptability of the species.

Socio-economic value

Value chain analysis of *M. stenopetala* products: the case of Gamo, Segen, S. Omo and Woleyta

zones selected woreda: This study aimed to investigate the contribution of *M. stenopetala* to the rural economy through undertaking the analysis of the determinants of moringa market supply and value chain analysis to develop value chain plan. The value chain model showed the contribution of *M. stenopetala* for the local or rural economy, moringa market supply and market access.

Table 6: Average willingness to pay (in Ethiopian Birr) for ecosystem provided by *M. stenopetala* (HH/year)

WTP for the service provided by <i>M. stenopetala</i> per/HH/Year	Study participants	Maximum	Sum	Mean	Mean $\pm$ SEM
Water purification	165	2000	148960	903	903 $\pm$ 40
Mitigating air pollution	181	5000	170000	939	939 $\pm$ 48
Reduction of soil erosion	208	5000	169300	814	814 $\pm$ 50
Wind protection service	215	6000	202990	944	944 $\pm$ 63
Enhancing soil fertility	196	2000	79390	405	405 $\pm$ 34
Future Direct and Indirect use value	217	9000	261500	1205	1205 $\pm$ 74
Recreation/ aesthetic service	210	6000	153880	733	733 $\pm$ 66
Educational value	162	5000	51000	315	315 $\pm$ 45
Cultural value	197	5000	81820	415	415 $\pm$ 42

Table 7: *M. stenopetala* production, income generation activity and market access in moringa growing districts of Southern Ethiopia (N=384)

Characteristics	Category of <i>M. stenopetala</i>	Frequency	Percentage
Number of <i>M. stenopetala</i> tree per households	2-3 tree	97.00	25.3
	4-5 tree	139	36.2
	Six and above	148	38.5
<i>M. stenopetala</i> supply to market	2-3 Kg	99	25.8
	4-5 Kg	136	35.4
	Six Kg and above	149	38.8
Production of <i>M. stenopetala</i>	Less than 3 Kg	97	25.3
	4-5 Kg	141	36.7
	six and above	146	38
Income from the sale of <i>M. stenopetala</i>	No income	94	24.5
	2-5 birr	150	39.1
	6-10 birr	42	10.9
	Above 11 birrs	14	3.6
Household's supply of <i>M. stenopetala</i> for market	2-3 Kg	99	25.8
	4-5 Kg	136	35.4
	Up to six Kg and above	149	38.8
Market access information for <i>M. stenopetala</i>	Yes	384	100.00
	No	0	0
Distance from market	$\leq$ 5Km	154	40.10
	11-20 Km	38	9.90
	above 20 Km	192	50.00
Market availability for <i>M. stenopetala</i> products	No	44	11.50
	Yes	340	88.50
Agricultural extension contacts and service access	No	44	11.50
	Yes	340	88.50

The study participants were farmers from moringa producing household heads and traders. The study revealed that all farmers had access to the market and information about the selling of *M. stenopetala*. Among the study participants, 40% of them get market access within 5 km distance, 10% within 11-20 km and 50 % above 20 km. Among the households, 39% had six and above trees and 36 had 4-5 trees in their farm-land and backyard.

The sources of *M. stenopetala* for the daily consumption in households of the study areas were from farm-land, back yard and purchasing from local market. Of the study households, 39% supply up to six and more kilograms to the market, 35% supply 4-5 kilograms and the rest 26% supply 2-3 kilogram to the local market (Table 7).

Perception of hotel food customers on existing practice, utilization and challenges of *M. stenopetala* in food establishment:

The study intended to generate information on the perception of respondents on nutritional, medicinal value and other contributions of *M. stenopetala* in food establishments. The study showed that all restaurants/hotels (food and drinking establishments) did not have moringa containing dishes in the menu of food items although few food establishments prepare moringa containing dishes for the visitors of the hotel. The major reasons for not incorporating moringa-containing dishes in the menus of the hotels and restaurants were food establishments related, attitude-related problems of customers and lack of sustainable and adequate supply from farmers of *M. stenopetala* for marketing moringa based foods. The value chain approach can create and or improve the opportunities available to the poor with a focus to increase small business holders' income and contribute to the local economy.

Discussion

Health and Nutrition

Effect of *M. stenopetala* consumption on biochemical parameters and physical measurement: The activity of the thyroid gland is predominantly regulated by the concentration of the pituitary glycoprotein hormone, thyroid-stimulating hormone (TSH) (Mariotti, 2011).

TSH stimulates the thyroid gland to synthesize thyroid hormone. Determination of T_3 , T_4 and TSH levels in the blood plasma is considered a substantive evaluation of thyroid function (Mariotti, 2011). Alterations in the normal levels of these hormones usually lead to physiological/clinical abnormalities, such as hypothyroidism and hyperthyroidism. The current study indicated that the mean T_3 , T_4 and TSH levels in adults and children in study participants who

did not consume moringa were within the reference interval or the normal range and clinical guide (Wu, 2006; Lohr et al. 2009; Katayev et al. 2010; Alberti et al. 2009; Ichihara 2014). The presence of adequate iodine (> 15 ppm) was detected in the majority of studied households' salts used for food preparation. Thyroid gland enlargement was not observed in the majority of households who consume (95.4%) and did not consume moringa (98.6%) during the examination of the household members for anterior neck mass. The findings demonstrated that *M. stenopetala* consumption did not cause a significant effect on thyroid gland function.

Biochemical markers are valuable tools for disease screening and diagnosis besides monitoring treatment effectiveness (Katayev et al. 2010). The current comparative cross-sectional study demonstrated that there was no significant effect on biochemical and physical parameters. The percentage of study participants with unconditional prevalence of blood pressure (Systolic blood pressure (SBP) $\Delta 140$ and or Diastolic blood pressure (DBP) $\Delta 90$ mmHg) were 7.9% and 15.5% in moringa using and non-using participants, respectively. Similarly, percentage with raised fasting blood glucose (≥ 126 mg/dl) and prevalence of metabolic syndrome at risk of cardiovascular disease (CVD) was 0.6% and 1.1% in moringa consuming and 8.6% and 13.1% in moringa non-consuming participants, respectively. The indicated values were within the 95% confidence interval range and normal reference range interval of the International Diabetic Federation consensus worldwide definition on physical measurements values (Ichihara 2014; Alberti et al. 2009). The majority of the study participants in both study sites were not at risk of metabolic syndrome for CVD (Chi-square and p-test 3.514, 0.12). This is attributed to the cross-sectional nature of the study that deals with one-time data collection and might be not appropriate to provide information over some time. The current findings, therefore, need to be substantiated with prospective longitudinal follow up and clinical trials to ascertain the medicinal values and effect produced by the frequent consumption of *M. stenopetala* on the biochemical and physical measurement values.

Status of vitamin-A in moringa consumption and non-consumption areas:

The prevalence of vitamin A deficiency in the moringa consuming group accounted for 10.18% with 95 % CI (5.40, 11.40) while in the non-consuming group was 19.85% with 95% CI (13.2, 23.0) (p-value < 0.005). The mean serum retinol level was significantly higher in *M. stenopetala* based diet consuming participants, which was 1.62 ± 0.77 with 95% CI (1.52, 1.70) as compared

with non-consuming participants with 1.24 ± 0.65 and 95% CI (1.16, 1.32).

This was also indicated by the laboratory test result that showed significant mean difference and the prevalence of vitamin A deficiency was higher in moringa non-consuming areas compared to consuming areas in both adults and under-five children. Dietary consumption of *M. stenopetala* based diet as food for the whole 7 days had higher mean serum retinol level of 1.88 (1.62, 2.15) compared to those who did not consume at all with 1.26 (1.18, 1.34). The mean serum retinol level in under-five children in the moringa consuming areas was $0.98 \pm (0.89, 1.05)$, whereas in the non-moringa consuming areas was 0.86 (0.76, 0.95).

The result showed that prevalence of vitamin A deficiency was significantly higher among participants in non-moringa based diet-consuming participants compared with consuming participants. This finding is supported by evidence from an interventional study conducted in Burkina Faso, which reported that significant improvement in serum retinol was observed after the intervention of participants by *Moringa oleifera* leaves powder consumption for one year (Zongo, et al. 2018). Vitamin A deficiency is a public health problem in developing countries including Ethiopia, which affects all dimensions of the population. Children and pregnant women are more likely to suffer from the deficiency (Akhtar et al. 2013; Gebreselassie et al. 2013). *Moringa stenopetala* leaves become dark green when cooked with cereals flour and the vitamin content is not lost during cooking even at higher temperatures (Abuye et al. 2003). From the findings, it may be suggested that *M. stenopetala* based food could be promoted to reduce vitamin A deficiency at the community level as a food-based intervention.

Assessment of undernutrition in *M. stenopetala* consuming and non-consuming areas: The lower prevalence of stunting, wasting and underweight in moringa consuming under-five children showed that the burden of undernutrition was relatively lower among this group compared to the non-consuming ones. The results of Height-for-age (HAZ) or stunting and the weight-for-height (WHZ) index that measures body mass with body height showed that there was a significant difference in stunting status in the comparative group relatively higher in moringa non-consuming areas compared to consuming areas ($p=0.03$). The above effect of the leaves of *M. stenopetala* is attributable to its outstanding source of vitamins A, B group and (C when raw) and minerals such as K, Fe, Ca, P and Zn protein and fats, which helps to overcome protein-energy malnutrition

(Yisehak et al. 2011). This finding is in agreement with that of an intervention study conducted in Burkina Faso in preschool children (Gelli et al. 2003).

There was no significant difference on underweight status in moringa consuming and non-consuming areas ($p=0.84$) on the prevalence of underweight (WAZ). The weight-for-age (WAZ) is a composite index of height-for-age and weight-for-height that accounts for both acute and chronic undernutrition. *Moringa stenopetala* has nutritional value since raw leaves contain 26.9% crude protein on dry matter basis and a higher percentage of carbohydrates, crude fibre, and calcium (Abuye et al. 2003). In the overall context, *M. stenopetala* consumption revealed a good index to overcome malnutrition which indicate the long- and short-term contribution of moringa consumption in intervening malnutrition.

Health facilities-based prospective follow up studies: The mean and SD of total cholesterol, low-density lipoprotein and triglyceride levels, and systolic blood pressure were lower in *M. stenopetala* consuming areas as compared to the non-consuming. These findings were in agreement with that of the study conducted on experimental animals (Geleta et al. 2016; Toma et al. 2016; Dadi et al. 2020) which indicated the beneficial effects for diabetes patients with raised blood glucose and lipid profile.

Frequent daily and weekly dietary intake of *M. stenopetala* based diet in the traditional food of *Kukufa* and *Fossese* besides using as soup and tea infusion had a more reducing effect on blood pressure (diastolic, systolic) and fasting blood sugar level compared to low frequent feeding habit for diabetic and hypertensive patients during the follow up prospective study. This finding was supported by a study done on animal model, which showed that aqueous extract of *M. stenopetala* produced a significant fall in systolic blood pressure, diastolic blood pressure, and mean arterial blood pressure at doses of 10, 20, 30 and 40 mg/Kg (Geleta et al. 2016). The comparative prospective follow up studies undertaken in diabetes and hypertensive cases demonstrated that the consumption of *M. stenopetala* will have health benefits for hypertension, diabetes and for hyperlipidemia

Health technology product formulation: The supplementation of *M. stenopetala* with locally available food grains could be an option to mitigate protein-energy malnutrition (PEM) and micronutrient deficiency. The formulated complementary food that contains *M. stenopetala* leaves could be scaled up to mitigate malnutrition and substitute imported expensive fortified foods and micronutrients.

The microbial growth on the leaf of *M. stenopetala* is a major challenge due to the high protein and fat content of the leaves. This difficulty was intervened by admixing *M. stenopetala* with medicinal herb adjuvants i.e., *Menta spicata*, *Cymbopogon citratus* and *Thyumus serralatus* that have antimicrobial effects against various microorganisms. The quality of the product was indicated by the absence of the indicator organisms, namely, *S. aureus*, *E. coli*, *Salmonella* species, *P. aeruginosa*, *K. pneumonia* and *C. albicans* and the acceptable limit of the total viable aerobic viable count, total mold and yeast count which are the quality indicators of consumables in the blended tea granules of *M. stenopetala*. The blend of *M. stenopetala* with adjuvant medicinal herbs that have good flavor and test improved the undesirable test of the leaves of *M. stenopetala* producing good flavor and taste thereby improving the palatability as depicted by sensorial acceptability tests of the tea infusion for taste, odor, flavor and mouthfeel. Furthermore, the blend of *M. stenopetala* with medicinal herbs can be considered as the preferred option to improve the stability of bioactive constituents of *M. stenopetala* during processing and storage.

The primary herb, *M. stenopetala* has the major focus on health action while the supporting or adjuvant herbs of the blend harmonize and preserve the primary herb by preventing microbial growth and chemical stability as determined by the evaluated physicochemical and microbial quality control parameters (European Pharmacopoeia, 2017; WHO, 1998). The tea infusions were found to decrease the blood sugar levels of mice that were induced with elevated blood sugar level showing its medicinal value for the management of pre-diabetic and pre-hypertensive patients coupled with exercise and appropriate nutrition. The tea granule blend of *M. stenopetala* with adjuvant medicinal showed good physicochemical, microbial quality properties and favorable preference ranking during sensory evaluation.

Toxicity studies of the herbal tea infusion showed no mortality and apparent signs of toxicity after administration of a single dose up to the dose of 2209.6mg/Kg in mice which showed the safety of *M. stenopetala* blended with the adjuvant herbs tea granule.

Agroforestry

Effect of plant spacing on growth and leaf biomass: The effect of spacing of *M. stenopetala* on green leaf production and branch biomass produced 38 kg/T, 4.92 kg/T and 74.71 kg/T GL, LL and BB, respectively. The higher production of green leaf biomass (LF), leaflet in a branch (LL) and branch

biomass (BB) in the wider space was due to less competition for nutrients and moisture than the narrow spacing between two trees. The wider spacing bears more branches than shoot elongation. This makes the plant bear higher lateral branches that increase the production of GL and LL than other spacing. Similar result was also reported by Ghosh et al. (2011), the finding indicated that higher plant biomass was recorded in wider spacing compared to narrow spacing under *Acacia auriculiformis* tree. The result demonstrated that *M. stenopetala* trees had higher leaf production and branch biomass in the agricultural field when managed properly together with annual crops, which helped farmers harvest both moringa trees and crops. The effect of plant spacing on growth performance and biomass carbon stock accumulation of *M. stenopetala* revealed that the height and diameter at breast height (dbh) of *M. stenopetala* were affected by different densities. Plant height increases with increase in plant density at the initial stage of the growth diameter but decreases with an increase in plant density in the remaining investigation period of the quarter.

Moringa stenopetala could play a significant role from the environmental point of view because it has the potential to produce an average of about 9.14 kg of carbon per plant for which it could trap about 33.48 kg of CO₂ and can produce 49.92 T per ha and 183.04 T per ha of carbon and CO₂, respectively. *Moringa stenopetala* has the potential to produce an average of about 9.14 kg of carbon/plant for which it traps about 33.48 kg of CO₂ and produce 49.92 T per ha and 183.04 T per/ha of carbon and CO₂, respectively. At the age of 1.5 yrs., it can produce annual carbon content of 5.48 kg by sequestering 20.09 kg of CO₂. These findings on the height growth were in line with the report of Sa et al. (2006). The traits in maize revealed that both *M. stenopetala* and *M. oleifera* tree species showed suppression of maize yield and yield components. Maize plants away from trees revealed significantly higher grain yield, biomass weight, cob number and cob length at both cropping seasons consistently. This could be due to sufficient sunshine intensity for photosynthesis which leads to good grain filling and subsequently better yield.

Maize grain yield reduction due to *M. stenopetala* ranged from 16% in the first cropping (2018) up to 23 % in the second (2019). Reduction of maize grain yields by *M. oleifera* trees was more drastic than in the plots with *M. stenopetala*, ranging from 32 % in the first cropping up to 48% in the second cropping season. This could be due to higher above and below-ground competition of *M. oleifera* than *M. stenopetala*. The study indicated that moringa-maize

intercropping systems are more financially attractive than maize mono-cropping.

Growth performance and carbon sequestration potential of *M. stenopetala* along an altitudinal gradient: The growth performance and carbon sequestration of *M. stenopetala* were significantly higher ($p < 0.05$) at a lower altitude as compared to mid and high altitudes. A similar growth pattern was also observed for all three-age classes. The significant higher growth at lower elevation may be due to its better adaptability to lower altitude and photosynthetic efficiency contributed by more exposure to light compared to higher altitudes. The amount of biomass that can be supported declines as the temperature is getting lower and lower with altitude. This is due to shorter growing periods. Moreover, CO₂ fixed per tree and CO₂ fixed per tree per year was found maximum at lower altitude (77.04 kg and 10.27 kg, respectively).

There was no observed significant variation for height among the three altitudes for age classes ($p > 0.05$). The height of the trees ranges between 6.08 m to 6.87 m. However, significant variation was found in the case of diameter for lower altitude with the highest diameter (0.34 m) followed by middle (0.18) and high (0.22) ($P < 0.05$). The middle and higher elevation did not show significant variation ($P > 0.05$). Maximum carbon (21 kg) was found sequestered at a lower altitude which is significantly higher than mid (6.66 kg) and high altitude (5.19 Kg) (Table 4). No significant variation for Carbon and CO₂ was observed among lower and mid-altitude. This finding was in line with the reports of Nawaz et al. (2017) in the study of 2 years old plantation of *Moringa oleifera* producing 0.8 kg Carbon, which trap 2.95 kg CO₂ and 1.47 CO₂/year ranked 8th among 15 species studied for Carbon estimation.

Therefore, *M. stenopetala* tree is not only contributing to the livelihood of the farmers of the areas but is also important from the environmental point of view.

The contribution of Moringa trees to the production of Alley maize: Agroforestry practices are an integral part of the farming system and practiced for economic, social and environmental benefits (Edwards et al. 2000). In the experimental plot-based study of moringa intercropped with maize, observation was made that maize plants in control plots (away from trees) revealed significantly higher grain yield, biomass weight, cob number and cob length at both cropping seasons consistently than intercropped with *M. stenopetala* ($p < 0.05$).

This may be attributable to sufficient sunshine intensity which leads to good grain filling and subsequently better yield through photosynthetic

reaction. The reduction of maize grain yields by *M. oleifera* trees was more drastic than in the plots with *M. stenopetala*, ranging from 32 % in the first cropping up to 48% in the second cropping season. This could be due to higher above and below-ground competition of *M. oleifera* than *M. stenopetala*. Furthermore, the sparse canopy of *M. stenopetala* could facilitate better penetration of sunlight for maize plants than *M. oleifera*. This could lead to getting better grain and biomass yield of maize intercropped with *M. stenopetala*. Reduction of maize grain yields for intercropped moringa tree was observed for both moringa species. However, yield reduction could be compensated by the outputs from moringa-maize intercropping systems compared to maize mono-cropping which is financially attractive due to securing products from moringa and maize. Therefore, integrating *M. stenopetala* with maize intercropping in their farming systems is a feasible option to generate income and other benefits derived from planted moringa trees.

Moringa based agri-silviculture system for agrobiodiversity conservation in the Konso-Derashe districts, South Ethiopia: Agrobiodiversity is the outcome of the interactions among genetic resources, the environment, and the management systems and practices used by farmers and herders. The frequencies of moringa trees and other woody species diversity indices are inversely proportional. Accordingly, Fasha kebele, which has the highest diversity, had less relative frequency of moringa (15.38%) than Gamole with ($H' = 2.12$ and $RF = 18.5\%$) and Holte with ($H' = 2.12$ and $RF = 25.6\%$). This indicates that farmers in Holte and surroundings plant *moringa* commonly for various purposes than Fasha and Gamole. *Moringa stenopetala* based agri-silviculture system is observed to be one of the most contributing systems for agrobiodiversity conservation in the Konso-Derashe district. This practice plays an important role for the *in-situ* conservation of biodiversity that supplies the basic and multipurpose products for rural households. The local people are the managers of natural resources and agrobiodiversity.

Facing future trends of food security problems, and increasing environmental uncertainty, *M. stenopetala* based agro-biodiversity conservation in farming systems through agroforestry the *ex-situ* conservation will have paramount importance for sustainable agriculture and for the protection of the natural forest. The result also revealed a vast integration of species diversity with respect to 18 crops and 22 woody tree species in a piece of land with a dominance of *M. stenopetala* tree. The diversity also varied among the districts. It is very impressive to observe such vast

integration of species diversity in a piece of land with *M. stenopetala*.

Impact of *M. stenopetala* tree on soil fertility status at Konso zone and Derashe woreda of Segen people's zone, South Ethiopia: No interaction effect was observed on soil pH between different age groups of *M. stenopetala* and distance from the tree trunk. This finding is in agreement with Manjur (2011) who indicated that there were no significant differences in soil pH under the canopies of *Faidherbia. albida* and *Croton macrostachyus* tree species as compared to open area. The slight increment in alkalinity under the canopy than in the open area could be attributed due to the breakdown of litterfall and dead roots from the tree, which means there was higher organic matter (OM) and humus under the canopy than the open area. This revealed influence of moringa tree on soil pH under the canopy at the distance of 2m from tree trunk of 5 years old age plant. Total nitrogen (TN) was rated similar across all different age groups and different distances from the moringa tree trunk (Table 6). However, higher TN under the canopy than the open area could be attributed to the successive decomposition of litter material and modified organic matter results in the formation of a more complex organic matter (humus).

The slight increment in alkalinity under the canopy than open area could be attributed to the breakdown of litterfall and dead roots from the tree, which means there was higher OM under the canopy than in the open area. For 10 years old moringa trees, both organic carbon (OC) and OM revealed a decreasing trend from trunk to open area. This result is in agreement with another investigation on different species (Yadessa et al. 2001) that reported significant reduction in OC and OM away from tree trunk to open cultivated land of *Cordia Africana* tree. Av. P showed decreasing trend for 5 and 10 years old moringa tree from canopy to open area. Moringa tree of 25years old at 8m distance from tree trunk rated optimum Av. P.

Cation exchange capacity (CEC) of the Konso and Derashe woredas study area ranged from 25.38 to 43.86, falling very high rating according to Hazelton and Murphy (2007) for different age groups and different distances from moringa tree trunks. The contents of total N and organic matter were highly significantly and positively correlated with each other. This is an indication of the direct dependence of total nitrogen content on the available content of soil organic matter.

Economic valuation of *M. stenopetala*

The value of environmental resources should be taken into account in economic decision-making processes as well as to achieve sustainable development.

Moringa stenopetala has significant economic contributions to the livelihood of millions of people in southern Ethiopia. Its benefit accrues the small-scale and resource-poor farmers. It has also the potential for the commercialization of its products. The commercialization of *M. stenopetala* products and the socio-economic benefits that it offers to the local community has not been well understood. There is data scarcity on the economic value of the existing resource, its productivity potential, the viability, and trends of the emerging business of *M. stenopetala*. The very few available data are not adequate to capture the overall economic picture. The information gap necessitates the need for resource-based assessment study to estimate the existing and potential of moringas resource is necessary. Attempts have, therefore, been made in this study to estimate the total economic valuation of the bioresources of *M. stenopetala*.

The total economic value (TEV) of an environmental resource (ecosystem) consists of its use-values (UV) and non-use value (NUV). The tree would help to rehabilitate the ever-diminishing forest resources in drier areas. The use value of *M. stenopetala* consists of direct use values and indirect use values. The direct use values of moringa included the provisioning of food (household food security), traditional medicine, recreation, source of income, fodder, fuel, etc., whereas indirect use value includes climate regulation, flood prevention, soil retention, air and water purification etc. Out of 220 study participants, 98.2 % (216) were farmers and the remaining 1.8 (4) respondents were merchants. The mean average intercropped size of land with *M. stenopetala* were 1.10 hectare.

The mean consumption of *M. stenopetala* leaves per week per household was 5.56 bundles. Of the respondents, 145 (65.9 %) sold *M. stenopetala* leaves at the local market and earn an average of 91.31 Ethiopian birr per week, which is 4565.5 for fifty weeks per year. Moreover, *M. stenopetala* is more preferable by the local communities for food consumption and traditional medicine than selling in the market. It was found that TEV of *M. stenopetala* per year per person was superior but did not meet the value of the genetic resource. This was due to lack of full understanding by the local community on the existence and bequest value of the plant areas. Regarding willingness to pay (WTP) for *M. stenopetala*, maximum willingness to pay was accounted from future direct and indirect use value prospects since the multipurpose nature of the plant makes people of the study areas pay in highest willingness. The least willing to pay was elicited from low-income earners who had little understanding on

the use-value of the plant. The survey showed the current market value of *M. stenopetala* leaves, and seeds were underestimated in a local market and do not reveal their actual value. The plant growth potential suitability analysis result indicated that different agroecologies of the country were found an ideal site for the growth and adaptability of the species.

Value chain analysis of *M. stenopetala* products in the case of Gamo, Segen, S. Omo and Woleyta zones selected woreda: All households in the study areas use fresh *M. stenopetala* for daily consumption. The sources of *M. stenopetala* for consumption in households in the study areas were from farmland, back yard and purchasing from local market. Financial, research and development efforts, awareness, perception and interest, regulatory approval are significantly affecting the production and marketing of moringa. In addition to the perishable nature of *M. stenopetala* leaves, variability in market price, quantity of risks, and seasonality may also be the constraints for the production and marketing of *M. stenopetala*. Limited access to capital markets, high consumer spending, and large family size are attributable to lower economic efficiency for the marketed driven production. According to the respondents of the study participants, low attention is given to improving and enhancing cultivation and productivity of *M. stenopetala*. It is a vital agroforestry plant in the study areas, it is being used as a staple food by the community and important for ensuring food security. There is no effective means of storage and preservation of *M. stenopetala* leaves at the community level during excessive production. So far, there is no effective means of preventing insect manifestation to prevent defoliation of *M. stenopetala* leaves.

The community should be motivated to plant *M. stenopetala* tree in the backyard and farmland through the support of agricultural extension. There is also need for health education on safe cooking methods of moringa leaves during preparation of traditional foods.

Understanding the cultural context of traditional based *M. stenopetala* staple foods, the perceptions and practices of customers and owners of hotels and restaurants could enhance its commercial value.

Perception of hotel food customers on existing practice, utilization and challenges of *M. stenopetala* in food establishment: *Moringa stenopetala* is a means of food source and contribute to the local rural economy of the community. There is no *M. stenopetala* containing dish in the menu of food items in the majority of food establishments in Southern Ethiopia. The reasons indicated for not including in the menu of moringa based foods were the

problem of sustainable supply of an adequate quantity of the leaves and the leaf cannot be stored for later use since it is rapidly perishable.

The supply of *M. stenopetala* from rural areas in local markets is usually immediately procured by the residents to fulfil the household needs and could not meet the need of restaurants. Some hotels serve *M. stenopetala* based traditional foods (*Kurkufa*, *Fossesse*) or as a vegetable when customers interest for same is expressed beforehand and ordered the food containing moringa. The local customers and residents are not interested to order moringa based foods since it is the staple food at their home. The demand for *M. stenopetala* containing dishes increased during the fasting times. Regarding the cost of moringa containing foods, respondents mentioned that the cost is relatively cheap compared to other foods. The market for moringa based food dishes in small hotels has an economical advantage since it serves as a means of income source. *Moringa stenopetala* is one of the potential agroforestry system that had an economic impact at household level as food and income sources. As it moves from household use to local market, it serves as a job opportunity for traders and low-class restaurant owners.

The multidisciplinary concerted investigation described in this paper on *M. stenoptala* through One Health and Eco-Health (OHEH) approach involving human-animal-plant interface facilitated to address the knowledge gap besides generating evidences for policy and program, and developing technology to maximize the benefits of *M. stenopetala*. Therefore, the use and conservation of *M. stenopetala* have to be properly exploited.

Conclusion

In light of the multipurpose use of *M. stenopetala*, the current multidisciplinary study resulted in revealing useful experiences and lessons. These include the value of moringa in food security, nutrition, medicine, economic development resource, agro-forestry and its environmental impact in arid and semi-arid areas. Its applicability for various purposes could be promoted for the benefit of the larger population. The research undertakings of this study are instrumental in developing health and other technology products besides agricultural packages in order to promote sustainable exploitation. The study findings could also promote and popularize *M. stenopetala* through government agencies and NGOs to facilitate its benefits and importance.

Conflict of interests

The authors declare that they have no conflicts of interest related to this article.

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Authors' contribution

The principal has compiled and written the draft manuscript. All authors have reviewed and edited the manuscript, and agreed on the final version of the manuscript.

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