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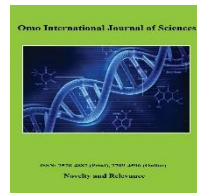
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Research Article

Traditional dairy production and milk handling practices in Mareka district, Dawuro Zone, Southwestern Ethiopia

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Abstract

This study aimed to assess traditional dairy production, management, and milk handling practices in the Mareka district of the Dawuro zone in southwestern Ethiopia. Samples included 96 dairy cattle-producing households across three agroecological zones. Data collection methods were structured questionnaires, observations, and discussions with key informants. Statistical analysis was performed using the Statistical Package for the Social Sciences. According to the study's findings, lactating cows constituted 28% of the overall herd population in the highlands and lowlands and 27% in the midlands. While 83% of households kept animals in the same house as their family, 15% housed them in the kitchen. Notably, cows in the highlands had a significantly shorter calving interval (17.3 ± 0.78 months) compared to the midland (24.5 ± 1.46 months) and lowlands (23.2 ± 1.58 months). Average lactation lasted 229.3 ± 6.69 days, with milking starting 51.6 days after calving. During peak periods, daily milk production per cow varied from 1.22 ± 0.06 liters in the lowland and midland to 1.63 ± 0.10 liters in the highlands. The average lactation yield per cow was 198.82 liters, with higher yields observed in highland cows, followed by midland and lowland cows. The study emphasizes the importance of empowering farmers and improving management practices to enhance the impact of traditional dairy practices on human nutrition and community livelihoods.

Keywords: Calving interval; Lactation length; Traditional dairy production

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1. Introduction

Ethiopia's traditional dairy farming sector benefits from favorable climate conditions, diverse native cattle breeds, and varied agroecological settings. The development of this sector holds significant potential for poverty alleviation and community nutrition enhancement in the country (Minten et al., 2020). Specifically, dairy development, particularly at the smallholder

level, can positively impact nutritional outcomes by increasing accessibility to milk and boosting household income (Randolph et al., 2007).

The dairy sector plays a crucial role in achieving two of the Sustainable Development Goals (SDGs), namely poverty reduction (SDG 1) and hunger eradication (SDG 2) (FAO et al., 2018). Rural women particularly benefit from dairy production as it generates cash and helps fulfill social obligations (Edemo, 2017).

The connection between livestock and nutrition, especially for children, is significant (Delay et al., 2020). Smallholder dairy farming households often exhibit better nutritional status, benefiting both mothers and school-aged children (Hoorweg et al., 2000; Walton et al., 2012). Moreover, women's ownership of livestock correlates positively with children's weight-for-age Z scores (Jin & Iannotti, 2014).

The characteristics of traditional dairy production serve as crucial indicators for the growth of the dairy sector in Ethiopia. The United Nations' SDGs underscore poverty eradication, hunger reduction, and sustainable resource management, aligning with the goals of dairy development.

While the challenges related to low cow productivity in Ethiopia are well-documented, there remains a gap in understanding the decision-making behavior and efficient resource utilization to enhance cattle production and reduce calving intervals. Despite the widely recognized importance of cattle in Ethiopia, system-specific data on cattle productivity and value are lacking, hindering our comprehensive analysis of these systems (Li et al., 2023). Additionally, the long-term impact of animal reproduction on human nutrition downstream is either underrepresented or concentrated in specific areas. This study aims to examine the causal relationship between dairy production, management techniques, and milk and milk product handling in Mareka district, Dawuro zone, southwestern Ethiopia.

2. Materials and Methods

2.1 Description of the study area

This research was conducted in Mareka District, located within the Dawuro Zone of the Southern Western Region of Ethiopia. The Dawuro Zone is bordered by the Woliya Zone to the east, the Gamo, Gofa, and Basketo Zones to the south, the Konta Zone to the west, the Oromiya Region to the north, and the Kembata and Tembaro Zones to the northeast. Mareka District occupies a central position within the Dawuro Zone. The administrative capital, Tercha, is

situated at coordinates 7°09'N and 37°30'E, approximately 500 kilometers southwest of Addis Ababa.

The Dawuro Zone encompasses a total land area of 446,082 hectares and is characterized by rugged, hilly, and mountainous terrain. Its primary forest cover, the Kechi-Yama-Dode-Kella natural forest, spans approximately 32,000 hectares. The Chebera Churchura National Park, located between the Dawuro and Konta Zones, enhances the region's biodiversity. The zone is intersected by several perennial rivers, all of which are tributaries of the Gojeb and Omo Rivers. Elevation within the zone varies significantly, ranging from 500 meters above sea level in the lower Omo Valley to 2,800 meters at the Tocha Tuta Ridge. The climate is marked by a mean annual rainfall of 1,500 mm and an average temperature of 20°C, with a bimodal rainfall distribution pattern.

The predominant agricultural system in the rural areas of the Dawuro Zone is mixed crop-livestock production. Key annual crops include maize, teff, sorghum, beans, peas, wheat, barley, haricot beans, sesame, taro, potatoes, and sweet potatoes, while perennial crops such as coffee, sugar cane, bananas, mangoes, and avocados are also cultivated. Enset (*Ensete ventricosum*) plays a pivotal role in the region's agriculture, supporting high population densities by providing substantial yields from small landholdings. It serves as a staple food source, particularly during periods when other crops are not yet mature or available in storage. Among tree species, eucalyptus has recently become invasive, affecting both arable and non-arable lands in the highland areas. Livestock production includes cattle, sheep, goats, equines, and poultry, with cattle serving as the primary source of milk. Dawuro kibe (butter) holds significant cultural value as an indigenous product. Mareka District was selected for this study due to its status as a commercial and agricultural hub within the Dawuro Zone, representing a significant portion of the zone's dairy production and marketing activities.

2.2 Sample size and sampling technique

Three kebeles (farmer's associations) were purposefully selected from the Mareka district to collect household data. These kebeles are named Waka, Gozoshasho, and Tarcha. Before selecting the kebeles, the district was stratified into three altitudinal categories such as highland, midland and lowland. From each agroecological zone, one kebele was randomly sampled (Table 1). The goal was to ensure representation from different ecological contexts. The percentage area coverage of the kebeles in agroecology was roughly similar throughout the district. Next,

households were randomly picked from each kebele based on their level of involvement in milk production, as well as the number and type of dairy animals they possessed.

Table 1. Proportion sample size in each unit (kebele) in the Mareka district

Agro-ecology	Altitude (m)	Kebele	Number of households
Highland	> 2200	Waka	32
Midland	1650-1900	Gozoshasho	32
Lowland	< 1450	Tercha	32
Total		3	96

2.3 Method of data collection

During the survey, both primary and secondary data were collected. Structured and pre-tested questionnaires were used to gather information directly from sampled households. The questionnaires were administered through house-to-house visits, involving direct interviews with farm families. Researchers conducted personal observations and engaged in discussions with key informants. Women, particularly those involved in dairying and having close interactions with cows, were specifically interviewed. Secondary data were obtained from relevant governmental and non-governmental organizations. These sources provided additional context and background information. The survey covered various aspects, including family sizes, dairy cow holdings, cows' production and reproduction performance, handling practices exercised by the family, milking utensils, and local herbs used for milk preservation and flavoring.

2.4 Data analysis

The data from the survey was analyzed using various descriptive statistics such as means, percent and frequency. The percentage of farmers (respondents) who had given similar responses to the questionnaire was calculated out of the total number of respondents who responded to each questionnaire. Those who did not respond to certain questions were excluded from the calculation.

Results of the statistical summary were presented in Tables. Some of the variables analyzed using the mentioned descriptive procedures include, household size, and reasons for the non-availability of cattle barns for farm households, and the population that utilizes warm water to make hygienic practices were summarized. The Statistical Package for the Social Sciences (SPSS) was used for data analysis.

3. Results and Discussion

3.1 Demographic characteristics

In the study area, the average family size was 7.29 members with minimum and maximum of 2 and 13, respectively. The average number of males and females per household under 15 years was 1.66 and 1.84; between 15 to 64 years was 1.83 and 1.84, respectively. The average number of females was slightly greater than males and the female-to-male ratio was 1.05: 1. The old age, above 64 years was very few in both genders. This study's average family size was comparable to those reported by Amejo et al. (2018) in the same locality (6.9 (SE=0.2)) and in the Alaba special districts of the SNNP region (6.7±0.18) (Kocho, 2007). However, it exceeds the national (5.2) and SNNP (5.1) area averages (CACC, 2003).

3.2 Agricultural features and dairy husbandry

Household holdings of the different categories of cattle were comparable in the three agroecologies (Table 2). The average number of lactating cows from the total herd population was 28% in the highlands and lowlands and 27% in the midlands, which exceeded all other herd structures included in the area, except for calf holding. Yoseph et al. (2003) reported the proportion of cows in urban and peri-urban dairy herd was higher than other cattle groups. It is unavoidable for a family to own at least one milking cow. Respondents stressed the importance of a dairy cow in the family as a breeding stock, nutritional source, and source of income for many small producers, particularly women.

According to FAO et al. (2018), dairy cow ownership and/or production improvement consistently had a substantial positive and nearly always statistically significant influence on a variety of parameters. Several research, countries, and indices give compelling evidence that dairying was the cause, not the effect, of increased household welfare. Whalen, (1984) stated that in the Ethiopian highlands, revenue from the sale of butter and cheese is the main source of income for women. In most traditional dairy production practices women are responsible for milk allocation and use part or all of the income from the sale of dairy products to purchase goods for the family.

According to Coppock (1994), Borana women in southern Ethiopia are responsible for milking animals, selling milk, and purchasing family necessities. Women's dairy product sales generate 20% of Borana's annual household income in southern Ethiopia (Holden & Coppock 1992). The Borana men in northern Kenya own and are responsible for the livestock. According to FAO (1979), women are responsible for caring for calves and small ruminants, milking cows,

processing milk, and using the revenues as needed. Similarly, Whalen (1984) reported that in the Ethiopian highland mixed crop-livestock production system, women are responsible for decision-making concerning dairy management such as watering, feeding, milking, cleaning animals and preparing beds, assigning young children to different activities, selling milk and using dairy income for household needs.

Table 2. Mean ($\pm$ S.E) cattle holding of households in three agroecologies of Mareka district

Group of cattle	Agroecology			Total
	Highland	Midland	Lowland	
Calves	1.6(0.10)	1.7(0.10)	1.4(0.12)	1.6(0.06)
N	30	32	32	94
Heifers	1.3(0.13)	1.6(0.17)	1.4(0.15)	1.4(0.09)
N	13	20	17	50
Bulls	1.1(0.10)	1.3(0.12)	1.6(0.2)	1.4(0.09)
N	14	21	14	49
Dry cows	1.3(0.1)	1.3(0.16)	1.4(0.12)	1.3(0.07)
N	19	14	18	51
Lactating cows	1.6(0.1)	1.7(0.10)	1.4(0.12)	1.6(0.06)
N	30	32	32	94

Furthermore, the community's nutritional needs necessitate the presence of at least one milking cow in the herd to supplement the family diet. A bread loaf prepared from enset (*Ensete ventricosum*), a commonly grown crop, or other cereal grains found in the research area is extremely difficult to make without milk and milk products. This type of cuisine demands an additional nourishing diet or recipe.

3.3 Cattle housing

Of the total respondents, 83% kept their animals in the same house where the family lived 15% kept them in the kitchen and only 2% housed them in a separate barn (roofed house) (Table 3). According to the respondents, the cattle herd is confined at night in the following order: oxen, bulls, heifers, dry cows, lactating cows, and calves, left to right. This setting facilitates indoor action and night milking. Calves are separately kept until the dam dries off to protect unwanted calf suckling.

There are several reasons for the respondents not to keep their animals in separate houses. The most important ones they claimed include, separately housing animals is not a cultural practice (22%), separately housing for animals is uneconomical (19%), keeping animals in the same house as humans protect animals from theft and/or wild animals (17%) or it protects animals from theft alone (13%). The other important attributes of the respondents such early identification of diseased animals when entering and living in the house, protecting animals from

cold stress and disease, making animals docile, facilitating immediate aid if they are sustained, getting personal satisfaction and protecting them and the owners from various types of harmful conditions accounts 12%.

According to Croney & Botheras (2010), the strength of the human-animal bond is likely to influence people's thought processes about how animals should be treated, because people form close emotional connections to animals they consider companions, and those relationships are likely to influence how they think about, view, and value other animals, including those used for food. Concerns about livestock animal welfare may stem from attitudes about companion animals (Croney & Botheras, 2010).

Table 2. Livestock housing in three agro-ecologies of Mareka district

Barn type	Agroecology [Frequency (%)]			Total
	Highland	Midland	Lowland	
Common house (human and animals)	19(60)	31(97)	30(94)	80(83)
Separate barn	2(6)	0(0)	0(0)	2(2)
Kitchen	11(34)	1(3)	2(6)	14(15)

3.4 Reproductive and productive performance of cattle

Cows in the three agroecological patterns were significantly different ($p \leq 0.001$) in the mean calving interval (Table 4). The overall mean calving interval of cows in the study area was 21.8 months, but cows in the highland had significantly shorter calving interval (17.3 ± 0.78 months) than those in the midland (24.5 ± 1.46 months) and in lowlands (23.2 ± 1.58 months). This may be due to a relatively better feeding condition in the highland areas. Highland cows may receive better feeding from residue and other supplemental feeds while lactating and thus may induce them to become in heat and conceive while they are still lactating. On the other hand, under range management conditions, especially when the nutrition is marginal, cows do not conceive while lactating and hence calving interval is extended (Mukasa-Mugerwa, 1989, Tegegne, 1981, Ash, 1991). Thus, the latter situation may be reflected in midland and lowland areas of Mareka district, Dawuro zone. Similarly, many studies showed prolonged calving intervals to cause significant problems in Ethiopia. For example, a study in Belesa, Northern Amhara region indicated that calving intervals of cows ranged from 2 to 4 years (Tessema et al., 2003).

The ideal calving interval for milk production in a dairy herd is 12 months (Peters, 1984; Gaines and Palfrey, 1931; Fetrow et al., 2007; DeLay et al., 2020). To achieve this target the management aspect must be very good; estrus detection must be in the best condition; and

depend on the cattle breed. Mekonnen & Goshu (1987) reported an average calving interval of 453 ± 106 days for indigenous Fogera cows in Gonder, which is shorter than the present study. On the other hand, the average calving interval of cows in the Dawuro zone was roughly comparable to 25 months reported by (Yilma & Ledin, 2000) for local cows in central highland mixed smallholder.

Table 4. Mean ($\pm$ S.E) reproductive and productive performances of cattle in three agroecological areas of Mareka district

Cows performance	Agroecology			Total
	Highland	Midland	Lowland	
Calving interval (months)	17.3 (0.78) ^a	24.5 (1.46) ^b	23.2 (1.58) ^b	21.8(0.83)
N	30	32	32	94
Milking start after calving (day)	50.0 (1.81)	53.91 (2.00)	50.8 (1.83)	51.6(1.09)
N	30	32	32	94
Lactation length (day)	243.0 (12.42)	233.4 (13.52)	211.9 (8.19)	229.3(6.69)
N	30	32	32	94
Peak milk yield period (day)	144.0 (8.56) ^b	113.4 (6.83) ^a	106.9 (6.99) ^a	121.0(4.57)
N	30	32	32	94
Lean milk yield period (day)	49 (8.6) ^a	65.2 (10.1) ^b	54.7 (5.5) ^{ab}	56.3(8.2)
N	30	32	32	94
Peak milk yield lit/cow/day	1.63 (0.10) ^b	1.22 (0.06) ^a	1.22 (0.06) ^a	1.35(0.05)
N	30	32	32	94
Lean milk yield lit/cow/day	0.76 (0.05) ^b	0.63 (0.02) ^a	0.62 (0.03) ^a	0.67(0.02)
N	30	32	32	94
Lactation milk yield/liters/cow*	271.96 ^b	179.5 ^a	164.3 ^a	201.07
N	30	32	32	94

*=Does not include calf off-take at either period, Row means with different superscripts are significantly different at $P < 0.05$.

In general, it is believed that calving rates and intervals in eastern Africa remain inefficient when compared to those obtained in the United States, Europe, and other countries with well-developed dairy businesses (DeLay et al., 2020). Many studies (Dahl & Hjort, 1976) discovered that normal calving rates were between 25 and 60%, with calving intervals of up to four years in many East African countries. While observed differences in the calving interval between cattle of Dawuro zone and the other stocks may be attributed to differences in management conditions and genotype of the cow. The mean lactation length in the study area was about 229.3 ± 6.69 days (Table 4). In most modern dairy farms, a lactation length of 305 days is commonly accepted as a standard. However, such a standard lactation length might not work for smallholder dairy cows in which the lactation length is considerably shorter in most cases (Masama et al., 2003; Teodoro & Madalena, 2003; Msangi et al., 2005). The study conducted by Alemu & Zinash, (2002) showed the average lactation length of a zebu cow to be 150-200 days. Probably farmers in

Dawuro milk cows until they are quite dry. However, this milking practice harms the calving interval, next-season milk and productive efficiency of the cow. Some scholars, however, argue that such an extended lactation period has practical significance for the smallholder dairy farmer as it provides compensation for the usually extended calving interval (Tanner et al., 1998). However, sometimes the profitability of short or extended lactation length gets the interest of the farm family in different ways. Men like cows dry off shortly and enter into the next gestation, whereas women need extended lactation. The former harvests calf crops from successive births while the latter needs to precede the ongoing lactation to fulfill the milk demand of the family. Numerous studies have documented that additional days in which cows are not pregnant beyond the optimal time post-calving are costly (Groenendaal et al., 2004; Meadows et al., 2005).

The average time lapse between calving and starting milking was comparable in the three agroecological levels (Table 4). On average farmers in Dawuro commence milking their cows after 51.6 days, which is a typical feature in the study area. Normally in most areas, cows are left not milked during the first week after parturition and in some cases, milking can be delayed at most until the middle of the second week. In Dawuro, farmers believe that allowing such an extended period of suckling improves calf growth and health. However, such a practice results in inefficient use of milk, and possibly the nutrition of the calf can be topped up using milk replacer and the milk can be made available for human use. Cows in the three agroecological areas of Dawuro significantly differed ($p < 0.01$) in the average length of peak milk yield period (Table 4). The mean length of the peak milk yield period in the highlands (144 ± 8.16 days) was significantly longer than in the lowlands (106.9 ± 6.99 days) and in the midlands (113.4 ± 6.83 days). Conversely, the average length of the lean milking period was shorter in the highlands than in the lowland and midland areas. The milking frequency was twice per day in all parts of the studied area mainly early morning and evening. Mean daily milk production per cow during the peak period was 1.35 liters with variation from (1.22 ± 0.06) liters in lowland and midland areas to (1.63 ± 0.10) liters in the highland and differences were significant ($p < 0.01$). Yilma & Ledin (2000) reported that indigenous cows' average daily milk yield of 1 to 1.5 liters in the central highland of Ethiopia. Similarly, daily mean milk/cow during the lean period was significantly higher ($p < 0.01$) in the highland (0.76 ± 0.05 liters) than in the midland (0.63 ± 0.02 liters) and lowland (0.62 ± 0.03 liters) (Table 4).

The average lactation yield across the study area is approximately 198.82 liters per cow. Highland cows produce significantly more milk, averaging 271.6 liters per lactation, followed by

midland cows at 179.5 liters, and lowland cows at 164.3 liters. These figures exclude milk consumed by calves during the initial two-month suckling period or during milking.

Various studies have shown that calves on average consume 32% of the total milk produced in rural small-scale production systems (Gebrewold et al., 2000; Feleke & Geda, 2001; Redda, 2001). As a result, the average lactation yield of cows in Dawuro obtained in this study could underestimate the true performance of the cows as they abstained from milking for quite an extended period (nearly 2 months) after calving. Thus, this may explain the low average lactation yield estimated in the present study compared to average values commonly reported for indigenous zebu cattle under a smallholder production system.

For instance, Ahmed et al. (2003) reported the average lactation yield for zebu cows to be range between 400 to 680 kg of milk/cow. On the other hand, the average yield estimated in the present study for highland cows in Dawuro (271.96 lit/lactation) was found to be on the upper range of the lactation yield reported by Alemu & Zinash (2002) in Ethiopia (200-250 lit/lactation/cow). However, the estimated average for the lowland and midland cows is still lower reflecting twofold effects of trypanosomes as well as the extended period of abstaining cows from milking, management and genotype effect.

3.4 Milking, milk handling and processing

3.4.1 *Milking and milk handling practices*

Cows are milked twice a day, in the early morning before breakfast and in the evening before dinner, across all three agroecologies (highland, midland, and lowland). Farmers noted that milking twice daily is a recent change because cows are producing less milk than before. In the past, cows were milked three times a day.

During milking, calves are allowed to suckle briefly to encourage milk flow and soften the teat. After this, calves are moved away and tied in front of their mother, where they can lick and sniff her, which helps keep the cow calm. If the cow becomes agitated, it may need to be tied to a pole. Calves are allowed to suckle again during milking to further stimulate milk flow. After milking, calves can continue suckling until the herd goes out to graze or the family starts other activities.

Cows are always milked indoors, either in the same area where they are housed with the family or in the kitchen where food is prepared. Farmers avoid milking cows outside, believing that moving them from their usual place can disrupt milk flow. Indoor milking is also considered cleaner, as outdoor environments may expose milk to dirt or other contaminants. Additionally,

insects or other disturbances outside can make cows nervous, which can reduce milk production. However, the milking areas were often muddy and unclean, and the cows' bodies were also dirty.

Table 5 shows the frequency of traditional hygiene practices during milking and milk handling. Most farmers (97% in the highland, 100% in the midland, and 100% in the lowland) wash their hands and milking equipment before milking. However, washing the cow's udder before milking is less common: 72% of highland farmers, 41% of midland farmers, and 50% of lowland farmers do this. Many farmers believe the calf cleans the teat by suckling, so they skip washing the udder. Washing the udder after milking is rare, practiced by only 9% of highland farmers, 6% of midland farmers, and none in the lowland. Typically, calves are allowed to suckle any remaining milk and clean the teat.

Table 5. Frequency in traditional hygienic practice during milk product handling in three agroecologies of Mareka district

Hygienic practices	Agroecology [Frequency(%)]			Total (n =96)
	Highland (n=32)	Midland (n=32)	Lowland (n=32)	
WH/WUBM/WE	22(69)	12(38)	16(50)	50(52)
WH/WE	7(22)	17(53)	14(44)	38(40)
WH/WUBMI/WE	0(0)	1(3)	2 (6)	3(3)
WH/WUBMI/WUAM	1(3)	0(0)	0(0)	1(1)
All*	1(3)	1(3)	0(0)	2(2)
All except WUBM	1(3)	1(3)	0(0)	2(2)

WH=Washing hand, WUBM =Washing udder before milking, WUAM=Washing udder after milking,

WUBMI=Washing udder before milking if dirty, WE=Washing equipment, *= WH/WUBM/WUAM/WUBMI/WE

None of the farmers filter the milk after milking. Instead, they mix it directly with previously collected milk in a container or use it for other purposes. Some farmers (13% in the highland, 3% in the midland, and 9% in the lowland) use warm water to wash the udder before milking. Additionally, 38% of highland households use warm water to clean milking equipment. Farmers cited lack of time, labor shortages, limited equipment, and the cow's habits as reasons for not using warm water to wash udders. Smoking dairy equipment is not a common practice in the study area. Ashenafi & Fekadu (1993) however indicated that smoked containers tend to lower the microbial load of milk contained therein as compared to unsmoked containers.

Table 6 shows households within and across the three agroecologies that used different types of milking equipment. Highlanders mostly used plastic containers for milking (41%) or clay pot (22%) or both clay pot and gourd (25%). In the midland, the majority used clay pots (56%) or both clay pots and gourd (25%) for milking, whereas in the lowlands, clay pots were exclusively used for milking by most households (82%) and usage of other types of equipment

for milking was fairly uncommon. In general, the use of plastic containers for milking was fairly common in the highlands than clay pots alone or together with gourd, whereas the reverse was true in midland and lowland areas. Early urbanization in the highlands and therefore availability of plastic containers has allowed the use of such equipment commonly by the highlanders. Gourd fruit plant grows and mixed social (such as potter maker) group inhabitants may provide the opportunity to frequently use gourd and clay pots in the midland and lowland areas.

Clay pot and gourd were most frequently used for the storage and fermentation of milk, however, variations were observed among the three agroecologies regarding the preference between the two types of equipment for storage and fermentation purposes. Households in highland and midland most frequently used clay pots to ferment milk (41% and 56%, respectively) followed by both clay pots and gourd (25% each) or gourd alone (16% each). Whereas in the lowlands, either clay pot or gourd alone was used for milk fermentation (40% and 47%, respectively) and households that used both equipment interchangeably were relatively few.

According to the key informants, the size of the clay pot and gourd used for milking, storage or fermentation, process, and churning varied greatly in size. For example, clay pots used for milking are locally called *butia* and in similar categories, equipment used for storage or fermentation and cheese making is locally known as *xarowa*. The size of these two equipment ranges from 1 to 3 liters. Most of the respondents said that they do not like to store or ferment milk in extra-large-sized clay pot. This is probably related to problems encountered during handling because of its large size and its sensitivity to easily damage. On the other hand, the gourd used for milking is locally called *bacha*, which is the smallest in volume. *Qaraba* is the respective name of the gourd in the area and is commonly used for storage and/or fermentation. *Qaraba* also used milk drinking purposes. The churn equipment locally called *Ma'nachia* is the largest in volume of all.

In all parts of the study area, *Ma'nachia* (churning gourd) is exclusively used for churning purposes. *Ma'nachia* with appropriate volume and wider mouth was selected for churning. Selected *Ma'nachia* is placed on the ceiling of the roof; dried for several days by the smoke and the vent is opened at one side of the neck, which is later used as a gas outlet. During churning, the mouth of *Ma'nachia* is packed tight with dried enset leaf. Churning is performed by women or female children sitting on a flat floor, stretching both legs one over the other, and gently rocking the *Ma'nachia* back and forth over the knee.

Table 6. Equipment used for milking, storage and processing of milk and milk products in three agro-ecologies of Mareka district

Equipment and their purpose	Agroecology [Frequency (%)]			Total
	Highland	Midland	Lowland	
Milking	n=32	n=32	n=32	n=96
Clay pot	7(22)	18(56)	26(82)	51(53)
Gourd	0(0)	3(9)	1(3)	4(4)
Plastic	13(41)	3(9)	2(6)	18(19)
Clay pot/ Gourd	8(25)	8(25)	2(6)	18(19)
Gourd/Plastic	3(9)	0(0)	1(3)	4(4)
Clay Pot/Gourd/Plastic	1(3)	0(0)	0(0)	1(1)
Fermentation	n=32	n=32	n=32	n=96
Clay pot	13(41)	18(56)	15(47)	46(48)
Gourd	5(16)	6(19)	13(40)	24(25)
Plastics	3(9)	0(0)	0(0)	3(3)
Metals	2(6)	0(0)	0(0)	2(2)
Clay Pot/ Gourd	8(25)	8(25)	4(13)	20(21)
Gourd/Plastic	1(3)	0(0)	0(0)	1(1)
Churning	n=27	n=28	n=30	n=85
Gourd	27(100)	28(100)	30(100)	85(100)
Cheese processing	n=27	n=28	n=30	n=85
Clay pot	27(100)	28(100)	30(100)	85(100)
Cheese storage	n=27	n=28	n=30	n=87
Clay pot	7(26)	11(32)	16(53)	34(39)
Plastics	1(4)	1(4)	3(10)	5(6)
Metals	3(11)	0(0)	0(0)	3(3)
Enset leaf	7(26)	0(0)	0(0)	7(8)
Clay Pot /Enset leaf	7(26)	18(64)	11(37)	36(41)
Clay Pot/Plastic	2(7)	0(0)	0(0)	2(2)

From the available total milk during the peak lactation period, 89% of household churn ergo to buttermilk and 89% make cheese from buttermilk (Table 6). The other respondents did not produce cheese or churn milk for a variety of reasons, including a lack of milk, the usage of whole liquid milk for household use, and a poor source of milk from a specific breed for cheese-making. Clay pots, enset leaf, and either clay pot or enset leaf made up 26% of cheese storage materials in the highland. In contrast, 37% of households in the midland and 53% of those in the lowland utilized clay pots to store cottage cheese. Furthermore, 64% of households in the midlands and 37% in the lowlands utilized a clay pot or an enset leaf to store homemade cheese. According to the respondents, enset leaf is common packaging material used to transport cheese to the market while clay pot is used for indoor storage purposes. During the wet season, enset leaf is known to host a variety of worms (adult or larvae), including snails, which can have an influence on both product quality and client health. On the other side, respondents asserted that

enset leaf used for cheese handling is wilted with fire or sunlight, which kills or dislodges the worms.

3.4.2 Fermentation

In the study area, fermented milk, called *meo'matha*, is made by adding fresh milk to previously stored milk without using a starter from earlier batches. Fermented milk is used to produce various products like cheese and buttermilk, which play important social roles, such as sharing with neighbors through a practice called *bik'ya*. This involves giving milk or dairy products during times of plenty and receiving them back during scarcity.

Butter, another fermented milk product, is vital in marriage ceremonies, used as cooking oil, food flavoring, hair and body cosmetic, medicine (applied nasally), and a source of income. Whey and other byproducts from churning are consumed by children of both genders. After calving, the cow's first milk, known as *qessa* (similar to colostrum), is collected, mixed with fenugreek, and stored for days before being shared with neighbors.

Table 7. Frequency distribution of factors that affect fermentation time of raw milk to *ergo* in three agro-ecologies of Mareka district

Factors	Agroecology [Frequency (%)]			Total (n=94)
	Highland (n=32)	Midland (n=31)	Lowland (n=31)	
Temperature	10(31)	15(48)	3(10)	28(30)
Cleaning material	0(0)	3(10)	1(3)	4(4)
Cow types	0(0)	2(6)	1(3)	3(3)
Lactation period	1(3)	1(3)	1(3)	3(3)
Disease of cow	0(0)	1(3)	0(0)	1(1)
Temperature/Cleaning material	5(16)	8(26)	8(26)	21(22)
T ⁰ /CM/DC	1(3)	0(0)	0(0)	1(1)
CM/CT/DC	1(3)	0(0)	0(0)	1(1)
T ⁰ /CM/CT/LP	2(6)	0(0)	2(6)	4(4)
T ⁰ /DC	1(3)	1(3)	2(6)	4(4)
T ⁰ /CM/LP	7(22)	0(0)	8(26)	15(16)
CM/CT	1(3)	0(0)	0(0)	1(1)
T ⁰ /CT/LP	1(3)	0(0)	0(0)	1(1)
T ⁰ /CM/CT	1(3)	0(0)	0(0)	1(1)
CM/LP	1(3)	0(0)	2(6)	3(3)
T ⁰ /LP	0(0)	0(0)	3(10)	3(3)

T⁰=Temperature, CM= Cleaning material, CT= Cow type, LP=Lactation period, DC=Disease of cow

Factors affecting milk fermentation time include temperature, equipment cleanliness, cow breed, lactation stage, and cow health (Table 7). Cool temperatures in the highlands (31%) and midlands (47%) slow fermentation compared to the warmer lowlands (9%). Unclean equipment can contaminate milk, leading to unwanted souring, but this is rare due to widespread cleaning practices. About 16% of highland and 25% of midland and lowland farmers noted that high

temperatures and dirty equipment together speed up milk souring, especially in the lowlands. Smoking milk containers, believed to reduce microbial growth, is not common, which may contribute to contamination.

The lean lactation period also affects fermentation, as milk has fewer organic components, slowing the pH drop needed for fermentation. This issue is minor, as milk is often used quickly during lean times. However, 22–25% of farmers reported that temperature, unclean equipment, and lean lactation together significantly impact fermentation, increasing milk loss if hygiene is poor. Mastitis, which lowers lactose and alters milk pH, and cow breed differences have minimal impact on fermentation, as noted by few farmers.

3.4.3 Cleaning and flavoring practices for milk equipment

Table 8 shows the most common plants used for washing milk equipment in the study area. In the highlands, 32% of households use *Ocimum hardiense*, 25% use either *Ocimum hardiense* or *Ruta cynopogan*, and 13% use *Ruta cynopogan* to clean milk utensils.

Table 8. Frequency distributions of plants and local herbs for milk and milk product handling in three agro-ecologies of Mareka district

Purposes and plants/ herbs	Agroecology [Frequency (%)]			Total
	Highland	Midland	Lowland	
Washing	n=32	n=32	n=32	n=96
Oh	10(32)	11(34)	8(25)	29(30)
Oh/Cc	1(3)	1(3)	10(31)	12(13)
Oh/Cs	0(0)	9(28)	6(19)	15(16)
Oh/Rc	8(25)	5(16)	2(6)	15(16)
Oh/Cm	1(3)	3(9)	0(0)	4(4)
Cc/Cm	0(0)	0(0)	5(16)	5(5)
Oh/Cyc	2(6)	1(3)	1(3)	4(4)
Oh/Cs/Cyc	2(6)	0(0)	0(0)	2(2)
Oh/Rc/Cyc	2(6)	0(0)	0(0)	2(2)
Cm/Rc	2(6)	0(0)	0(0)	2(2)
Rc	4(13)	2(6)	0(0)	6(6)
Flavour/Taste	n=24	n=23	n=29	n=76
Oh/Cs	1(3)	1(3)	1(1)	3(4)
Rg	17(53)	16(50)	28(88)	61(80)
Tfg	2(6)	0(0)	0(0)	2(3)
Oh/Rg	4(13)	0(0)	0(0)	4(5)
Rg/Cs	0(0)	6(19)	0(0)	6(8)

Cs= *Coriand sativum*, Cc= *Chenopodium chenopodiaceae*, Cm= *Cymbopogon martini*, Cyc= *Cymbopogon citralus*, Oh= *Ocimum hardiense*, Rg= *Ruta graueolens*, Rc= *Ruta cynopogan*, Tfg= *Trifolium foenum graecum*

In the midlands, 34% of households use *Ocimum hardiense*, and in the lowlands, 25% use it for the same purpose. Plant materials for cleaning are more varied in the lowlands, likely due to greater plant diversity in that area. Ayantu (2006) noted that gulowa (*Achyranthes*

aspera), tenadam (*Ruta graveolens*), and kosoratya (*Ocimum hardiense*) are used to clean milk vessels for milking, storing, and processing. Most households grow these plants in their backyards or source them from nearby areas, with women primarily handling these tasks.

The survey found that 76% of households use flavoring plants for milk and dairy products. Tenadam (*Ruta graveolens*) is the most common flavoring herb, used by 53% of highland, 47% of midland, and 88% of lowland households. Additionally, 6% of highland households use fenugreek for flavoring. Ayantu (2006) reported that 16.7% of households in Delbo Atwero, 6.1% in Zala Shasha, and 14.1% in Delbo Wegere kebele mix butter with spices. Similarly, tenadam (*Ruta chalepensis*) and garlic (*Allium sativum*) are commonly used in processing and storing traditional cottage cheese (Aleganesh, 2002).

4. Conclusions

Agriculture, encompassing crop cultivation and livestock production, is vital for livelihoods in rural Dawuro, supporting household income, nutrition, and social well-being. Cattle, particularly lactating cows, are central to these systems, with comparable numbers across highland, midland, and lowland agroecologies. However, reproductive and productive performance varies, with highland cows exhibiting shorter calving intervals and higher lactation yields compared to those in midland and lowland areas. Highland cows also experience longer peak milk yield periods but shorter lean phases. These differences likely result from disease prevalence and suboptimal management practices. Prolonged calf suckling, while beneficial for calf health, may underestimate lactation yields and reduce milk available for human consumption and sale. Reassessing suckling duration is necessary to balance calf welfare with economic outcomes. During peak milk production, 89% of households process milk into butter and cottage cheese, enhancing income and dietary diversity. However, lean periods limit milk availability for processing, constraining economic benefits. Collaborative milk pooling among small-scale producers could ensure sufficient quantities for processing, improving income through stable product sales in distant markets. Regional extension services should prioritize comprehensive dairy management practices to enhance productivity across agroecologies. Proactive adoption of sustainable practices, rather than reliance on provisional support, will empower farmers and strengthen agricultural systems in Dawuro.

Conflict of Interest

The authors declare no conflict of interest.

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Research Article

Intercropping legumes covers with maize on soil moisture improvement in selected dry land areas of Basketo Zone, Ethiopia

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Abstract

Intercropping provides sufficient scope to include two or more crops simultaneously on the same piece of land, targeting higher land productivity. There is limited experimental evidence on the benefits of intercropping systems, which remains largely unstudied. This study was conducted to evaluate the effect of intercropping on soil moisture conservation in a moisture-stressed area. For this study, a randomized complete block design was used to establish experimental plots with three replications. Five treatments were evaluated, including maize only, lablab only, cowpea only, lablab with maize, and cowpea with maize. Disturbed soil samples were collected from a depth of 0–30 cm and composited for soil moisture and physicochemical property analysis. The yield and biomass of maize and legume shrubs were collected from each plot, and the variations were analyzed using the general linear model. The land equivalent ratio (LER) was computed to evaluate land productivity. The result showed that higher soil moisture content was recorded on maize-cowpea intercrop (34.33%), followed by maize-lablab intercrop (31.20%) relative to sole maize (26.83%) at the development stage in the first-year trial. This implies the benefit of legume shrubs on soil moisture conservation, both under mono-cropped and intercropped conditions. In this trial, the highest LER values were obtained for maize intercropped with Lablab 1.44 at Angila 4 kebele, while at Angila 3 kebele, the highest LER values were obtained for maize intercropped with cowpea 1.29. Therefore, conducting similar studies for more than two years on permanent field plots is vital to achieving considerable changes in soil moisture and soil physicochemical properties, as well as helping farmers make better use of cereal-legume intercropping systems to increase yields in moisture-stress areas.

Keywords: Intercropping; Legume; Land equivalent ratio; Soil moisture; Yield

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1. Introduction

The global population is expected to continue to grow, resulting in a significant increase in food, feed, and fuel demand (Ramankutty et al., 2018). Most smallholder farmers in sub-Saharan Africa often grow cereal crops such as maize (*Zea mays* L.) in a continuous monoculture to support their livelihood, even when productivity and profitability is limited (Baudron et al., 2012b). Under the current agricultural production system in sub-Saharan Africa, it might be very challenging to meet the food and nutrition requirement of the growing population, with the challenges of climate change and variability, land degradation, and infertile soils (Ngwira et al., 2012). As a result, agricultural production requires a shift towards more sustainable cropping systems to help reverse soil degradation and improve production and productivity (Esther et al., 2017).

In Ethiopia, about 90 percent of the total population depends on subsistent agriculture system. It is a leading sector as a source of income, home consumption, employment, and foreign exchange. Agricultural output is also used as an input for industries, so it can stimulate industrialization (Tariku et al., 2018). However, Ethiopia's agriculture land productivity has been decreasing in alarming rate. This can be ascribed to soil degradation and in efficient water resources utilization. Even in years of abundant rainfall, the country's is unable to produce enough grain to feed its population (Kassa, 2003). Sustainable intensification in agriculture seeks to optimize efficiency and reduce losses within crop production systems (Van Ittersum et al., 2016). Intercropping is recognized as a viable agricultural practice within semi-arid regions, with the potential to improve household food and nutrition security while minimizing the negative impacts of continuous cereal mono-cropping (Rapholo et al., 2020). Intercropping can increase aggregate yields per unit area, insure against crop failure particularly in dry regions and enhance the efficiency of land-use by complete and complementary utilization of nutrients (Li et al., 2014). Studies have shown that soybean (*Glycine max* L.) intercropped with maize increased land equivalent ratio (1.25-1.46), which indicates that intercropping can increase crop yield (Xu et al., 2020). In addition, intercropping is an effective way to stabilize crop yield and reduce N input (Luce et al., 2015).

According to (FAO, 2011) to reduce rural poverty and maintain food security, soil fertility needs to be maintained, and agricultural systems need to be transformed to increase the productive capacity and stability of smallholder crop production. Greater attention is thus being given to alternative means of intensification, particularly the adoption of intercropping. Cereal-

legume intercrop systems are particularly beneficial in marginal sub-Saharan African landscapes, which are characterized by high levels of malnutrition, resource limitations, and rainfall variability. In this region, intercropping systems are indispensable for food and nutritional security in resource poor region (Smith, 2017). More importantly, intercropping with legumes is highly effective in conserving soil moisture, reducing soil erosion and sustaining soil fertility (Cheer et al., 2006). The use of legumes in intercropping systems can improve N-use efficiency and total biomass under reduced chemical fertilizer input (Xu et al., 2020). When intercropped with maize, cover legumes such as cowpea (Bayer et al., 2000), and lablab (Janet et al., 2014) could significantly contribute to soil moisture conservation and increased soil productivity compared to mono cropping.

Across moisture stress areas, like Basketo Special Woreda of Ethiopia, crop failure is common. Thus, farmers have been trying to cope with this problem by using mulches of crop residues. This is also challenging because crop residues are used as feed for animals and energy for cooking. Therefore, using the advantages and opportunities of cover legumes as an intercrop in moisture stress areas could solve the problems simultaneously. Moreover, the contribution of legume to the soil nutrient balance, to improve soil moisture content through reducing evaporation and reduce soil erosion. However, the impacts of legume intercropping have not been well tested in the study of agroecological conditions. In addition, there is limited experimental evidence on the mechanisms underlying benefits of intercropping systems and belowground interactions in intercrops remain largely unstudied. Therefore, this study aimed to evaluate the effect of intercropping different legumes (Cowpea and Lablab) with maize towards soil moisture conservation and crop yield improvement in moisture-stress areas.

2. Materials and Methods

2.1 Description of the study area

The study was conducted for two consecutive years (2020 and 2021) at Basketo Special Woreda in the South Nation Nationalities and People's Regional State of Ethiopia (Figure 1). The woreda is characterized as a moisture stress area. The altitudinal location of the special Woreda ranges from 780-2200 meter above sea level. Temperature of the Special Woreda ranges from 15°C-27°C and its mean annual rainfall ranges from 1000-1400mm (Tariku et al., 2018). The experimental plots were established in Angila-3 (6°16'125"N, 36°33'34"E) and Angila-4 (6°17'17"N, 36°33'39"E) kebeles (Figure 1).

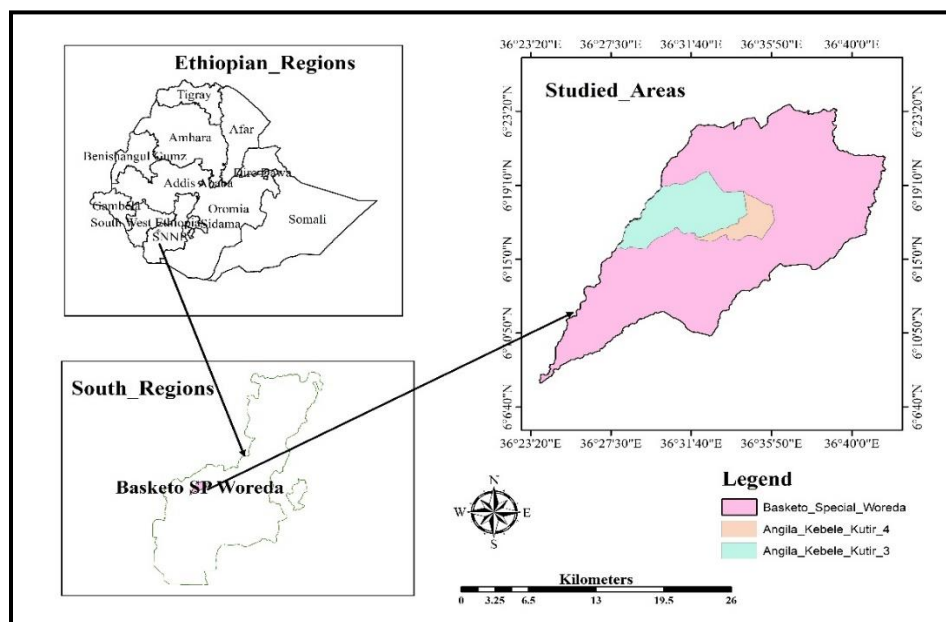


Figure 1. Location map of the study area

2.2 Research design and treatments

The study was conducted at Angila 3 and Angila 4 kebeles to test the impacts of maize-legume intercropping on soil moisture and crop yield. The experiments were laid out in randomized complete block design (RCBD) with five treatments with three replications on each farmer's training center. Five treatments were applied in this trial: (T1) maize alone, (T2) sole cowpea, (T3) sole lablab, (T4) maize intercropped with cowpea, and (T5) maize intercropped with lablab. The experimental field was prepared by using oxen driven local plow (Maresha). The plot size of the trial was 5m×5m (25m²) and one meter walkway between blocks and plots. Maize was planted based on the recommended spacing (80 cm and 40 cm) between rows and plants, respectively. Leguminous shrubs (Cowpea and Lablab) were sown on one row between maize with spacing of 40 cm and 30 cm between rows and plants respectively. Seed rate used was 25kg/ha for both lablab and cow pea under monocultured conditions and 75% of leguminous seed rate under intercropped conditions. 100 kg of NPSB ha⁻¹ was applied at planting. We used a total of 75 kg of Urea twice, i.e., 50 kg was applied during planting of maize and legume crops and the remaining amount (25 kg) was applied after 35 days of planting. NPSB and Urea was used as a source of Nitrogen, Sulphur, Boron and Phosphorous. For this study, we used BH-140 maize variety. All leguminous shrubs were sown simultaneously with the maize. The treatments were maintained and repeated on the same plots and for the second season by protecting the experimental plots from livestock grazing as well as crop residues after harvesting was left on

the plots in the first season. All agronomic management practices, such as weeding, pest control, etc., were performed during the trial period per the research recommendations for maize and legume crops.

2.2.1 Data collection

2.2.1.1 Soil sampling

To monitor the soil moisture status of each plot, disturbed soil samples were collected from the intra-row spacing of the intercropped plots from five sampling points at a depth of 0-30 cm at three stages at (planting, development stage and harvesting). Similarly for the non-intercropped plots, a sample was collected from the intra-row spacing from there different sampling points. Then, a composite soil sample was prepared for all plots. The weight of the wet soil sample was measured at site using digital scale and then taken to the laboratory. Then, the soil was oven-dried at 105°C for 24 hour. Finally, the gravimetric method was used to determine the soil moisture content in grams, which was then converted to a volumetric base using the following (Eq. 1).

$$SMC = \frac{W_w - W_d}{W_d} \quad (1)$$

Where SMC, soil moisture contents %; W_w , weight of wet soil (gm); W_d , weight of dry soil (gm). In addition, at sowing time composite subsurface soil sample was collected to determine the soil physico-chemical properties of the study sites. However, at harvesting time subsurface soil samples were collected separately from each plot (treatment based) for the analysis of soil physico-chemical parameters (soil pH, organic-carbon concentration (OC), total nitrogen concentration (TN), availability of Phosphorus, availability of potassium and exchangeable acidity was analysed.

2.2.1.2 Crop data

Grain yield and biomass of maize and legumes were determined by harvesting an area of 4m x 4m (16 m²) from the total plot area of 25 m² and converted into tonnes per hectare basis. Grain yield was adjusted to 12.5% moisture level; whereas plant biomass was weighed after leaving it in open air.

2.3 Data analysis

The collected data were subjected to one way analysis of variance (ANOVA) using SAS software and least significant difference (LSD) was used to test significance of means differences at $p \leq 0.05$ levels.

For intercropped plots, land equivalent ratio (LER) was calculated to determine total production. LER was estimated using the following relationship (Eq. 2) (Willey & Osiru, 1972);

$$LER = \frac{Y_{Mint}}{Y_{Msol}} + \frac{Y_{Lint}}{Y_{Lsol}} \quad (2)$$

Where, Y_{Mint} = Yield of maize under intercropping conditions; Y_{Msol} = Yield of maize under sole crop conditions; Y_{Lint} = Yield of legume under intercropping conditions and Y_{Lsol} = Yield of legume under sole crop condition.

3. Results and Discussion

3.1 Effect of intercropping on soil physicochemical properties

Table 1 presents we analyzed and documented the baseline condition of soil physicochemical properties. We found that before experiment in experimental sites according to (Tekalign, 1991); Soil OM or OC ratings, the soil property values of %OC are between 1.5-3.0, %OM is between 2.59-5.17 which are under medium rates and total nitrogen is between 0.05 - 0.12 which are under low rates accordingly, in both the study site the availability of total nitrogen was under low rates. The surface soil pH values varied from 6.25-6.56 and rated as slightly acidic. The textural classes of the surface soils at both experimental sites were silty clay loam and loam (Table 1).

Table 1. Physicochemical properties of the soil under experimental site before the experiment (2020)

Study site	Parameters								Texture		
	pH (H ₂ O)	EC (ds/m)	OC (%)	OM (%)	TN (%)	C:N ratio	Av.P (ppm)	%Sand	%Clay	%Silt	Textural class
Angila 3	6.25	2.39	2.79	4.79	0.11	13.95	27.9	41.6	22	36.4	Loam
Angila 4	6.56	1.85	2.44	4.13	0.10	11.62	23.2	20	38.6	41.4	Silty clay loam

pH=Power of hydrogen, NT=Total Nitrogen, OC=Organic Carbon, OM=Organic matter, Av.P=Availability of Phosphorus, EC= Electrical conductivity, C:N= Carbon-to-Nitrogen ratio

The result from experimental plots showed the surface soil pH values increased at the experimental site of Angila 4 and were rated as neutral in all treatments relative to maize monocropping (Table 2). Soil organic matter content of surface soils were varied from 2.6-5.2% at baseline condition (i.e., prior to experimental trials) (Table 1) and rated as moderate ranges (Berhanu, 1980). The result also showed high ranges >5.2% of organic matter in maize intercropping with lablab (6.67%) and in monocropped conditions of Cowpea (6.57%) in Angila 4 as well as monocropped conditions of Lablab (5.63%) in Angila 3 after the experiment (Table 2). Our finding is also similar to rating described by (Tekalign, 1991). Soil organic matter content can alter and improve the physical, chemical, and biological properties of soils, then

helps to increase plant productivity. This is because of the intercropping of legume crop and the fast mineralization of nitrogen from the organic matter. The distribution pattern of total nitrogen across experimental sites were similar to that of soil organic matter, since soil organic matter content is a good indicator of the available nitrogen status in the soil. According to (Havlin, 1999) total nitrogen content of soils is categorized as low (<0.15%), medium (0.15-0.25%), and high (> 0.25%) which revealed that, in both study sites the availability of total nitrogen was rated as medium (Table 2) and it was also similar with (Tekalign, 1991) ratings.

Table 2. Physico-chemical properties of soil after experiment (2021)

Studied sites	Treatments	Parameters								
		pH (H ₂ O)	EC (ds/m)	OC (%)	OM (%)	TN (%)	C:N ratio	A.v.P (ppm)	CEC (mg/kg)	Av. K (mg/kg)
Angila 3	Maize only	6.4	0.11	2.27	3.91	0.19	11.95	20.7	86.76	7.4
	Lablab only	6.3	0.14	3.27	5.63	0.22	14.86	21.0	85.86	6.17
	Cowpea only	6.3	0.11	1.93	3.32	0.20	9.65	22.0	58.46	7.0
	Maize + Lablab	6.4	0.12	2.88	4.95	0.21	15.16	18.0	76.5	7.87
	Maize+ Cowpea	6.5	0.12	2.70	4.64	0.22	12.27	19.0	55.97	8.08
Angila 4	Maize only	6.50	0.22	2.93	5.04	0.16	16.28	28.0	86.76	7.4
	Lablab only	6.85	0.20	2.38	4.10	0.18	14.0	27.6	85.86	6.17
	Cowpea only	6.91	0.22	3.82	6.57	0.19	20.11	32.0	58.46	7.0
	Maize + Lablab	6.73	0.21	3.87	6.67	0.20	22.76	33.7	76.5	7.87
	Maize+ Cowpea	6.75	0.18	2.70	4.64	0.21	12.86	27.8	55.97	8.08

pH=Power of hydrogen, NT= Total Nitrogen, OC=Organic Carbon, OM=Organic matter, Av. P=Availability of Phosphorus, Av. K= Availability of Potassium, EC=Electrical conductivity, C:N= Carbon-to-Nitrogen ratio

3.2 Effect of intercropping on soil moisture

Soil moisture and water availability to plants are determining factors in intercropping systems. Efficient water use leads to the use of other resources. Higher soil moisture content was recorded on maize cowpea intercrop (34.33%) followed by maize lablab intercrop (31.20%) as compared to sole maize (26.83%) at development stage in the first year trial (Figure 2). Similarly, higher soil moisture content was recorded on maize cowpea intercrop (28.16%) followed by maize lablab intercrop (25%) as compared to sole maize (19.45%) at development stage at second year trial (Figure 3). Similar study was also found by (Ayele, 2020) in Bena-Tsemay district, South Omo zone; Southern Ethiopia where intercropping of maize with cowpea had better soil moisture contents during active crop development stage. Soil moisture content in the soil was lower in the sole crop of maize this may be due to high evaporation potential, whereas in maize intercrop

with cowpea and lablab was high due to low evaporation potential in both growth stages and trial years.

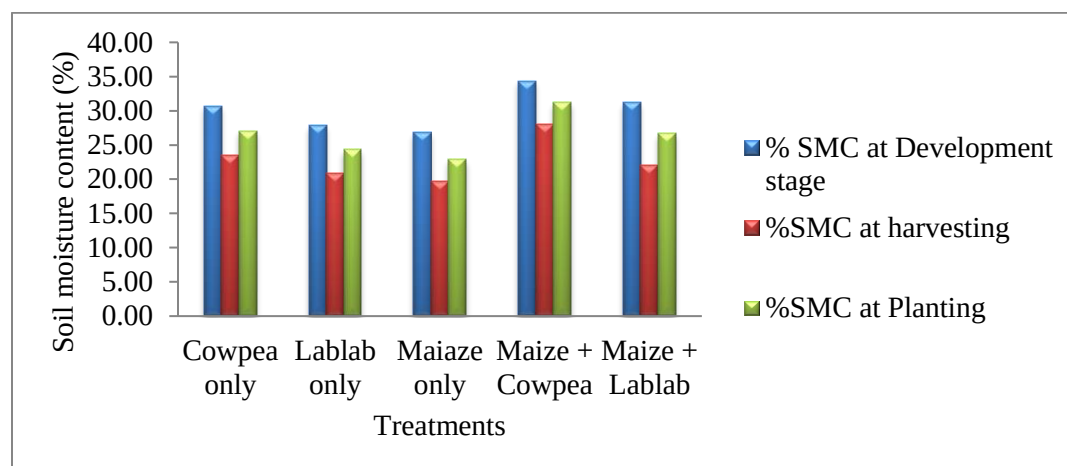


Figure 2. Effects of intercropped maize-legume covers on % soil moisture content (SMC) at first year in 2020 (Angila 4 kebele)

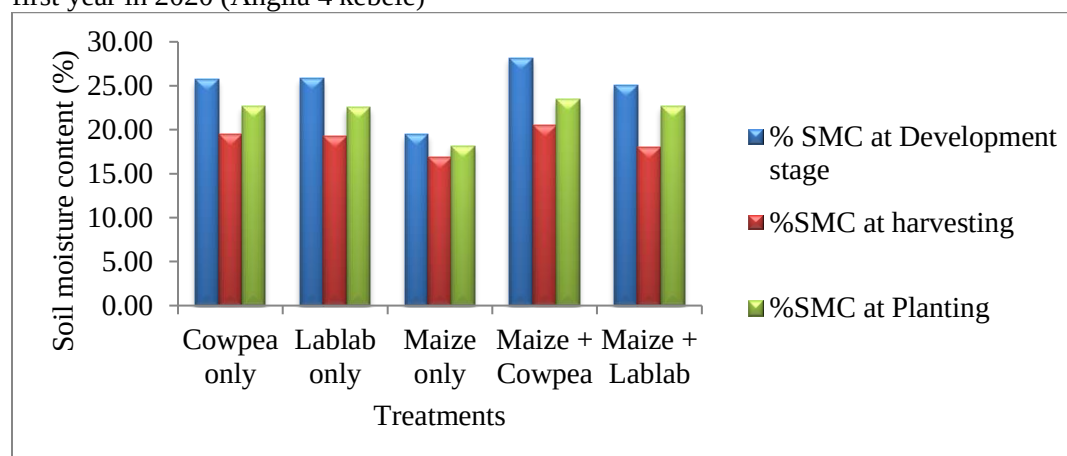


Figure 3. Effects of intercropped maize-legume covers on % soil moisture content (SMC) at second year in 2021 (Angila 4 kebele)

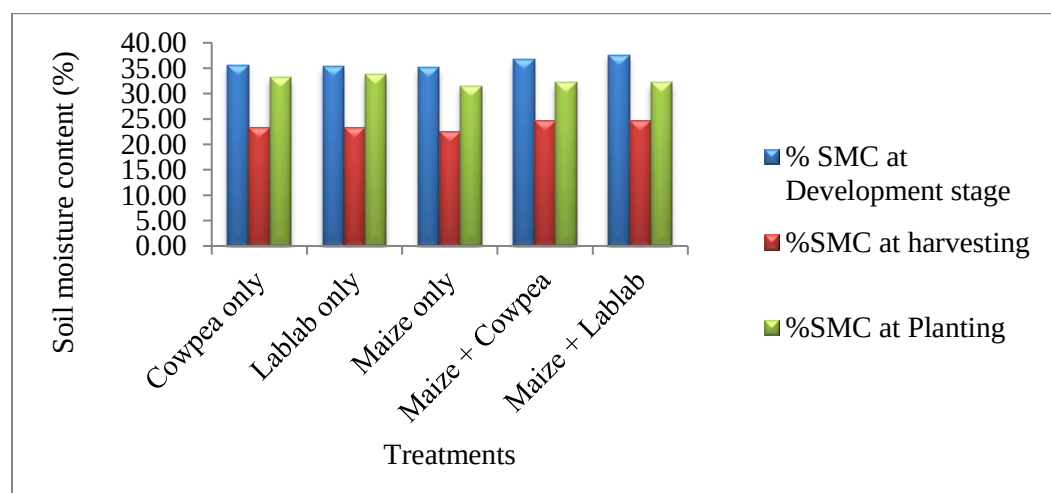


Figure 4. Soil moisture contents (SMC in %) at different growth stage at Angila 3 kebele for one year trial in 2021

The study result also corresponds with a study by (Bayer et al., 2000); when intercropping maize with cowpea and intercropping maize with lablab (Janet et al., 2014) could significantly contribute to soil moisture conservation and increased soil productivity compared to sole maize cropping. The soil moisture content did not differ significantly at planting and harvesting stages in Angila 3 Kebede ($P < 0.05$). However, better result was obtained by maize-lablab intercropped conditions (37.6%) followed by maize-cowpea intercrop (36.8%) at the development stage (Figure 4). The present result was supported by a study of (Sagar et al., 2020) revealed the combination of maize-cowpea intercropping can assure greater light interception and check evaporation loss of soil moisture than a pure stand of maize. A study conducted by (Bagegnehu et al., 2021) at Misrak Azerinet woreda, southern Ethiopia also revealed that, intercropping maize with legumes have comparable soil moisture content at development stage. Soil moisture and water availability to plants are determining factors in intercropping systems, and efficient water use leads to the use of other resources. Scientific investigations have shown that the maize-legume combination registered greater water use efficiency than that of sole crops, and under water stress conditions, it could be one of the best options (Sagar et al., 2020).

3.3 Effect of intercropping on yield and yield components of maize

The analysis showed that there was a significant difference in grain yield of sole maize and intercropped conditions of maize with lablab and cowpea in the growing season of 2021 at Angila 4 kebele, as well as between sole maize and intercropped condition of maize with lablab at Angila 3 kebele (Table 3). A study by Sagar et al. (2020) noted that higher yield in maize-cowpea intercropping combination than in pure stand. The study also indicated that the plant height of maize was not significantly different ($P < 0.05$) in both cropping seasons and sites, and other studies also reported similar results (Ayele, 2020 & Arun, 2016). In the study conducted in Bena-Tsema Woreda, Southern Ethiopia by Biruk et al. (2021) reported as there is no significant effect of intercropping on plant height and cob length of maize plant. Similarly, in terms of maize biomass, the study also revealed that there was a significant difference ($P \leq 0.05$) in both trial sites in the year 2021 between sole maize and intercropped condition of maize with lablab and cowpea.

However, there was no significant difference in biomass among cropping systems in the first year trial ($P \leq 0.05$) in Angila 4 kebele, which was inconsistent with the study by (Ayele, 2020). The study showed that higher value in grain yield and biomass was recorded under sole

cropping. Non-significant effects in all growth parameters and maximum values were observed in sole cropping system over that of intercropped in the study by (Nigussie & Daba, 2022).

Table 3. Grain yield and biomass of Maize under legume shrub

	Angila 4 (1 st year/2020)			Angila 4 (2 nd year/2021)			Angela 3 (1 st year/2021)		
	Ph(m)	Bm(t/ha)	Gy(t/ha)	Ph(m)	Bm(t/ha)	Gy(t/ha)	Ph(m)	Bm(t/ha)	Gy(t/ha)
Maize + Lablab	2.31	13.8	7.2	2.24	26.13 ^b	3.67 ^b	2.40	25.63 ^b	3.40 ^b
Maize + Cowpea	2.23	11.8	5.5	2.23	27.90 ^b	3.97 ^b	2.33	26.23 ^b	4.30 ^{ab}
Maize only	2.16	16.14	7.35	2.15	35.53 ^a	5.07 ^a	2.28	33.27 ^a	5.27 ^a
LSD (0.05)	ns	Ns	ns	ns	5.5	0.66	ns	6.4	1.7
CV (%)	5.7	15.5	14	5.1	8.1	6.7	6.5	9.9	17.8

Ph=Plant height, BM= Biomass, Gy= Grain yield, ns=not significant. Mean values with different letters within the column are statistically different at $P \leq 0.05$.

3.4 Effect of intercropping on yield and yield components of legumes

The analysis showed that there were significant differences in biomass and grain yield of legumes in both cropping systems (i.e., monocropped and intercropped) in both growing seasons and trial sites ($P \leq 0.05$). In monoculture, the yield of legumes was higher, whereas the lowest yield was obtained when legumes were intercropped with maize (Table 4). As reported by (Chemed, 1997) higher grain yield was recorded under sole cowpea compared to intercropping. Competition for water, nutrients and shading are maybe the factors that reduced cowpea yield under high numbers of maize plants in intercrop (Lesoin & Francis, 1999).

In terms of biomass as shown in (Table 4) there were significant difference between sole cowpea and intercropping cowpea with maize in both growing season and trial sites. Biruk et al. (2021) also reported that total biomass of cowpea was significantly influenced by cropping system

Table 4. Grain yield and biomass of cowpea and lablab

Treatments	Angila 4 (1 st year/2020)		Angila 4 (2 nd year/2021)		Angela 3 (1 st year/2021)	
	Bm/ton/ha	Gy/ton/ha	Bm/ton/ha	Gy/ton/ha	Bm/ton/ha	Gy/ton/ha
Cowpea + Maize	28 ^b	0.14 ^b	16.70 ^b	0.18 ^b	17.0 ^b	0.45 ^b
Cowpea only	41.45 ^a	1.06 ^a	26.28 ^a	0.53 ^a	25.33 ^a	0.96 ^a
LSD (%)	10.5	0.8	6.8	0.12	7.5	0.4
CV (%)	8	37	9	9.8	10.2	17.6
Lablab + Maize	4.2 ^b	1.46 ^b	30.53	1.10	22.07	0.50 ^b
Lablab only	5.77 ^a	2.5 ^a	38.4	1.53	33.37	0.93 ^a
LSD (0.05)	0.95	0.5	ns	ns	ns	0.37
CV (%)	5.43	7.42	10.7	13.5	13.4	15

Ph= Plant height, Bm=Biomass, Gy= Grain yield; ns=not significant. Mean values with different letters within the column are statistically different at $P \leq 0.05$.

A study result by (Baudron et al., 2012b) described that, total biomass of (maize + cowpea) intercrops was higher than in sole maize or cowpea stands and biomass production and is seen as a benefit of intercropping in mixed crop-livestock systems, which are characterized by competing uses of crop residues mainly for livestock feed and for maintaining soil organic matter. Hauggaard et al. (2001) also reported that legume-cereal intercropping performance indicates yield advantages and greater yield stability as compared to legume sole cropping.

3.5 Effect of intercropping on land use efficiency

Land equivalent ratio is the most common index adopted in intercropping to measure land productivity. It is often used as an indicator of the effectiveness of intercropping (Seran & Brintha, 2009b). Any value greater than 1.0 represents that a yield advantage for intercropping. In this trial, as shown in (Table 5), the highest LER values were obtained for maize intercropped with Lablab 1.44 in the second trial year at Angila 4 kebele inturn, indicating that 44% more area would be required by sole cropping system to equal the yield of the intercropping pattern. While, in Angila 3 kebele there is highest LER values or yield advantages were obtained for maize intercropped with cowpea 1.29 (Table 6) which indicats that, 29% more area would be required by sole cropping system to equal the yield of the intercropping pattern. Therefore, this showed that land was effectively utilized under maize-legume intercropping and is more advantageous than for sole cropping. A LER greater than 1.0 has been reported with bean-maize intercropping by (Saban et al., 2007). A study by Biruk et al., 2021 showed that, LER was greater when maize intercropped with cowpea. Mashingaidze (2004) also revealed that, land was effectively utilized under intercropping and yield was improved.

Table 5. Land equivalent ratio (LER) of intercropping of maize with legume crops at Angila 4 kebele

Treatments	Yield (ton/ha) first year				Yield (ton/ha) second year			
	Maize	Lablab	Cowpea	LER	Maize	Lablab	Cowpea	LER
Maize + Lablab	7.2	1.46	-	1.55	3.67	1.10	-	1.44
Maize + Cowpea	5.5	-	0.14	0.88	3.97	-	0.18	1.12
Maize only	7.35	-	-		5.07	-	-	
Cowpea only	-	-	1.06		-	-	0.53	
Lablab only	-	2.5	-		-	1.53	-	

Consistently (Amede & Nigatu, 2001) received the LER value of 1.5. Similarly (Stoltz & Nadeau, 2014) showed that intercropping commonly leads to a higher protein content compared to monocropped maize and higher yield on a LER >1 basis compared with maize monocropped. Intercropping can increase aggregate yields per unit input, insure against crop failure particularly

in dry regions and enhance the efficiency of land-use by complete and complementary utilization of nutrients (Li et al., 2014). Esther et al. (2017) who have conducted both on-station and on-farm study revealed that, the total yield was higher in the intercrops than the sole crops of either maize or cowpea and most intercrop treatments had LER > 1 pointing to the greater land use efficiency of the maize-cowpea intercrop system compared to sole cropping.

Table 6. Land equivalent ratio (LER) of intercropping of maize with legume crops at Angila 3 kebele

Treatments	Yield (ton/ha) first year			LER
	Maize	Lablab	Cowpea	
Maize + Lablab	3.40	0.50	-	1.18
Maize + Cowpea	4.30	-	0.45	1.29
Maize only	5.27	-	-	
Cowpea only	-	-	0.96	
Lablab only	-	0.93	-	

4. Conclusion

It is concluded that intercropping cereal with legumes plays a considerable role in enhancing soil moisture content compared to the pure stand of cereal. In terms of LER, the highest values were obtained by maize intercropped with cowpea and Lablab in both trial sites. That is why intercropping helps keep nutrients on the field and improves available soil moisture. It is recommended that farmers practice intercropping for better soil moisture content improvement by maize with Lablab and cowpea than a pure stand of maize. In the case of Angila 4 and areas with similar agro-ecology, it is recommended that farmers intercrop maize with Lablab. However, in Angila 3 and areas with similar agro-ecology, stallholders should intercrop maize with cowpea. Hence, for better productivity of the intercropping system, further study should be done by considering other factors of production.

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Conflict of Interest

We declare no potential conflict of interests.

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Research Article

***Ezo_ote* (ILRI_5527A): Registration of high-yielding dual purpose oat variety for Ethiopian agriculture**

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Abstract

The forage dry matter, seed yield, and fodder quality were found to be far below their potential in Ethiopia. One possible reason may be the limited availability of stable, high-yielding quality forage varieties in the mid- and highlands of the country. A field study was conducted to assess and introduce stable, high-yielding, and disease-resistant oat varieties. Eleven genotypes were compared at four locations (Arba Minch, Areka, Bonga, and Hawassa) during the 2018 and 2019 cropping seasons. Then, the performance of *Ezo_ote* (ILRI_5527) was verified on farms and on-stations and compared with two standard checks (SRCPX80AB2806 and SRCPX80AB2291) during the 2020–2021 main cropping seasons. The *Ezo_ote* (ILRI_5527A) variety performed better in most agronomic traits than both standard checks. *Ezo_ote* (ILRI_5527A) had an average dry matter yield of 12.59 t/ha, a seed yield of 3.6 t/ha, and a crude protein yield of 1.48 t/ha. The yield advantages of dry matter yield, seed yield, and crude protein yield were 8 and 21%, 0 and 9%, and 22.12 and 77.78% over the SRCPX80AB2806 and SRCPX80AB2291 varieties, respectively. Moreover, the new variety had shorter days of flowering and forage harvesting, and was resistant to septoria net blotch and yellow rust diseases. Therefore, *Ezo_ote* was found to be a superior oat variety in the checks and other trial varieties. The National Variety Release Committee (NVRC) approved *Ezo_ote* (ILRI_5527A) as a dual-purpose crop variety for cultivation and research in mid to high altitudes of Ethiopia.

Keywords: *Avena sativa* L; Crude protein yield; Dual purpose; *Ezo_ote*; ILRI_5527A

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1. Introduction

Ethiopia is ranked fifth worldwide in cattle ownership and tenth in livestock ownership (MOA, 2022). However, the country's livestock productivity is hindered by insufficient fodder and is largely dependent on low-quality pastures and crop residues (Shapiro et al., 2015). This leads to a modest average milk yield of 1.48 liters per cow (MOA, 2022).

Oat (*Avena sativa* L.), which is extensively cultivated as a cereal crop, is primarily harvested for green fodder, hay, silage, and seeds (Singh et al., 2018). Oats serve not only as a significant food source for humans, but also as feed for livestock (Iannucci et al., 2016). In Ethiopia's highlands, oats thrive under rain-fed conditions with minimal inputs (Beyene et al., 2015). They are particularly well-adapted for feed production in cool, wet climates with low-fertility soils, outperforming other cereals (Marshall et al., 2013). Oats yield higher biomass, between 12.5-13.1 t/ha, in acidic soils (Atumo & Kalsa, 2020). They are also cultivated in winter, providing green forage during periods of scarcity. Oat grain, a balanced concentrate, is included in the diets of poultry, cattle, sheep, and other livestock (Mehta et al., 2015). Remarkably, oat grains can yield up to 2.1 t/ha (Atumo & Kalsa, 2020), with higher yields reported in diverse growing conditions (Peltonen-Sainio et al., 2008).

Oat crops produce a range of products used in animal feed, human consumption, and industrial materials (Stevens et al., 2004). These products, obtained from various parts of the crop, can be collected at different stages of growth, such as whole crop silage, straw, grain, and grain by-products (Marshall et al., 2013). Oats are exceptionally nutritious, providing high-quality protein with a lower energy content, making them ideal for certain types of animal feed (Mengistu et al., 2016). However, the production of forage seeds has not received adequate attention in national research and development programs (Atumo & Jones, 2021). Importantly, mixtures of oats and vetch can yield a crude protein content of 17.0%, sufficient to support the growth of calves and milk production (Molla et al., 2018).

In southern Ethiopia, livestock production is challenged by a feed shortage amounting to 34.4 tons/year in dry matter (DM), 57.9% in crude protein (CP), and 62.6% in metabolizable energy (ME), according to FAO 2018. The agricultural sector has historically placed little emphasis on forage crop enhancement, resulting in a scant number of forage varieties being released and registered in Ethiopia, as reported by EAA in 2021. Nonetheless, there was a notable increase to 72 officially registered forage crop varieties in 2021 (36 grasses, 28

herbaceous legumes, and 8 browses) from just 29 varieties in 2011. These varieties represent a mere 4.94% of all crop varieties developed in Ethiopia over the 50-year tenure of the Ethiopian Institute of Agricultural Research (EIAR) since 1976. In contrast, improved oat varieties have been shown to yield a high dry matter output and could potentially nourish twice the number of animals per unit area compared to conventional fodder crops. Selecting oat varieties that are high-yielding, of optimum quality, disease-resistant, early-maturing, and suitable for stressed soil conditions is vital in regions like South Ethiopia, Sidama, Central Ethiopia, and Southwest Ethiopia. This paper aims to detail the performance of the newly released oat variety '*Ezo_ote*', providing valuable insights for stakeholders involved in food and forage oat production in Ethiopia.

2. Materials and Methods

2.1. Description of study areas

The study was conducted during June 2018 through March 2020 *Belg* cropping season at Ezo ote, Gamo South Ethiopia (Arba Minch Agricultural Research Center (AMARC); Doyogena, Kembata Central Ethiopia (Areka Research Center); Adiyio, Kefa South West Ethiopia (Bonga Research Center); and Hulla, Sidama Region (Hawassa Research Center) highland areas. Ezo oe at Arba Minch Research Center located at 6°18'32' N, 37°33'E and altitude 2985 meter above seas level with an annual rainfall 1857.9 mm, minimum temperature 15.6°C and maximum temperature 26.3°C.

The soil pH of Ezo Ote is 4.8 with textural class of clay loam (Atumo & Kalsa, 2020). Doyogena at Areka Research Center located at 7°21'68' N, 37°47'E and altitude 2535 meter above seas level with an annual rainfall 1823.13 mm, minimum temperature 13.98°C and maximum temperature 24.49°C. The soil pH of Doyogena is 6.5 with textural class of clay loam (Abebe, 2014). Adiyio at Bonga Research Center located at 7°17'361'' N, 36°22'00'' E and altitude 2473 meter above seas level with an annual rainfall 2042.4 mm, minimum temperature 14.1°C and maximum temperature 23.1°C. The soil pH of Adiyio is 5.2 with textural class of clay loam (Wodebo et al., 2023). Hulla at Hawassa Research Center located at 6°27'001'' N, 38°34' E and altitude 2100 meter above seas level with an annual rainfall 1200 mm, minimum temperature 11.2°C and maximum temperature 18.2°C. The soil pH of Hulla is 6.0 with textural class of clay (Teramage et al., 2023). The study area map (Figure 1) also illustrates the geographical locations of the sites.

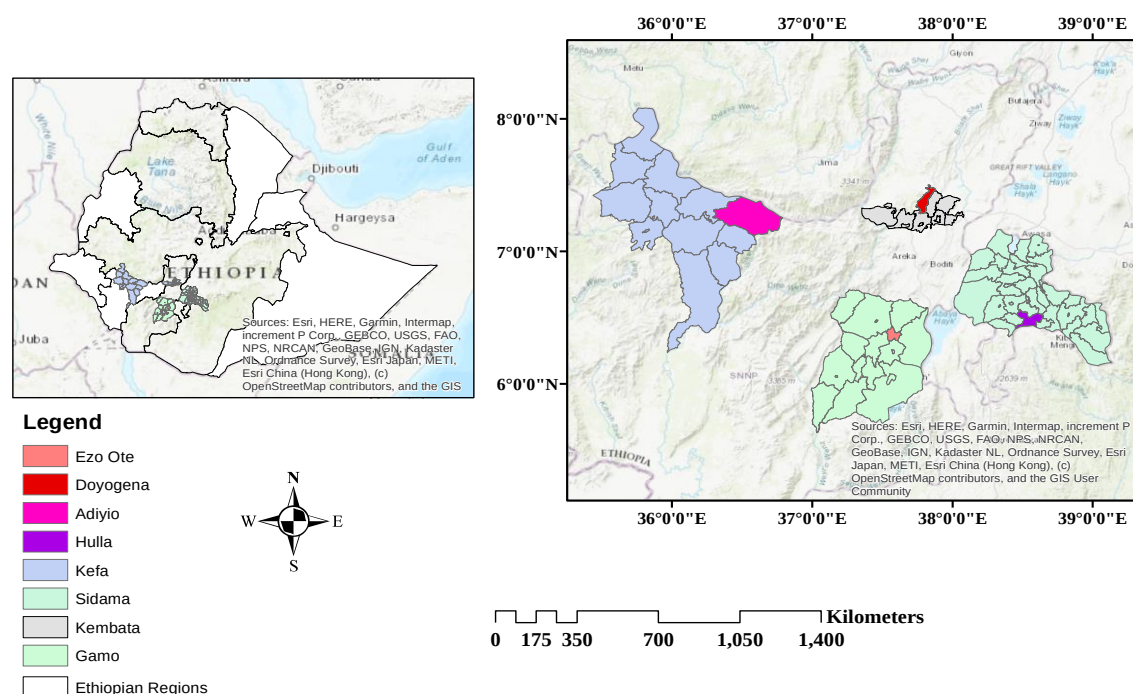


Figure 1. Study area map

2.2. Experimental units and designs

The experiment consisted of 11 treatments of oat genotypes namely ILRI-5431A, ILRI-5444A, ILRI-5490A, ILRI-5499A, ILRI-5526A, ILRI-5527A, ILRI-15152A, ILRI-15153A, ILRI-16101A, SRCPX80AB2291 and SRCPX80AB2806 which were laid out in randomized complete block design with three replications on well prepared and leveled field at four regions (South Ethiopia, Central Ethiopia, South West Ethiopia and Sidama) of the country. All the treatments were randomly allocated to different plots in each replication.

Nine accessions from international livestock research institute (ILRI) were selected in consultation with the ILRI gene bank manager based on previous experience and consideration of which accessions may be most suitable to perform in the selected environment and the other two varieties were recently released at Holeta Agricultural research center used as standard check. The seed was sown in 10 rows of 3x2 m plot lines 20 cm spacing using drilling method in each location from Early July to mid-July each year. Rows were 3 meters long and blocks were spaced 1.5 meter apart. The seed rate used was 100 kg/ha. Blended fertilizer (NPS 100 kg/ha) of nitrogen, phosphorus and sulfur at the rate of N19%, P38% and S7% was applied with 50% of urea (50 kg/ha) applied at planting while the remaining 50% urea at mid-tillering of the

crop. All relevant agronomic and quality data was collected from the four middle rows, seed data was from the rest four rows and the two rows were served as a border.

2.3. Origins of the genotypes under evaluation

The history of eleven oats genotypes presented in Table 1. Nine oats accessions were originated from United States of America and stored in the repository of ILRI forage gene bank. Other two varieties listed under number 10 and 11 are the oat varieties released by Holeta Agricultural Research Center (HARC) in 2015. The breeder seed of those varieties/ genotypes were maintained at their respective breeding center or gene bank.

Table 1. Origin, other name, DOI, seed source and year of release of the genotypes used under National Variety (NVT) evaluation

No.	Genotype/ Accession #	Other Name	Origin	DOI	Seed source		Year of release
					Gene bank	Breeder center	
1	15152	'Moore'	-	10.18730/FTEFF	ILRI	-	-
2	15153	'Saia'	-	10.18730/FTEGG	ILRI	-	-
3	16101	-	-	10.18730/FVA19	ILRI	-	-
4	5431	IFAV 189	USA	10.18730/G53JF	ILRI	-	-
5	5444	IFAV 291	USA	10.18730/G540X	ILRI	-	-
6	5490	IFAV 346	USA	10.18730/G55K6	ILRI	-	-
7	5499	IFAV 358	USA	10.18730/G55WF	ILRI	-	-
8	5526	IFAV 421	USA	10.18730/G56T8	ILRI	-	-
9	5527 (<i>Ezo_ote</i>)	IFAV 422	USA	10.18730/G56V9	ILRI	AMARC	2022
10	SRCPX80AB2291	-	-	-	-	HARC	2015
11	SRCPX80AB2806	-	-	-	-	HARC	2015

2.4. Variety evaluation procedures (NVT)

Preliminary yield trial was conducted during 2016 and 2017 for nine accessions collected from ILRI forage gene bank and five released varieties to select for high dry matter and seed production in Ethiopia production season (Atumo & Kalsa, 2020). During 2018 and 2019 national variety evaluation (NVT) was conducted for nine accessions aside to two standard check varieties at four locations.

Therefore, the genotypes were exposed to be evaluated under eight (four by two) environments. According to the Ethiopian crop variety register guideline (MOA, 2000), after selecting superior candidate ILRI_5527A genotype, officially communicate with Ethiopian Agriculture Authority for variety verification at field level by assigning verification technical committee. Depending on the report from the compiling center National Variety Release Committee Variety release Form 1 filled and submitted to the former Plant Variety Release,

Protection and Seed Quality Control Directorate under Ministry of Agriculture and Natural Resources now Ethiopian Agriculture Authority.

2.5. Variety verification procedures (VVT)

Based on the overall performances, the one better-performing oat variety (*Ezo_ote*/ILRI_5527) was promoted to a variety verification trial with two recently released checks SRCPX80AB2291 and SRCPX80AB2806. The four locations were at Arba Minch, Areka, Bonga and Hawassa Agricultural Research Centers during the main cropping season in 2021. The variety verification specific sites were Kemba and Ezo Ote (Arba Minch research center), Doyogena (Areka research center), and Alargeta (Bonga research centers) during 2021. In 2021 main cropping season, ILRI-5527A as candidate variety *Ezo_ote*(ILRI_5527A) along with SRCPX80AB2806 and SRCPX80AB2291 as standard check varieties was planted in the locations of NVT under on farm and on station condition in eight environments for variety verification (VVT). Each variety was planted in 10 m by 10 m (100 m²) plot as to the standard of National variety releasing guideline (EAA, 2021). The national technical committee (TC) of National Variety Release (NVRC) observed and evaluated the variety in the field condition. ILRI-5527A is the traditional cultivar/landrace of USA found in the repository of ILRI forage gene bank (Table 2). As presented in Figure 1, the ILRI-5527A accession was found to be superior to the existing oat varieties for yield (dry matter, seed and crude protein), forage quality and other desirable agronomic traits.



Figure 2. Field performance of new oats variety at verification in the study areas

The varieties were planted in rows of 25 cm apart on a plot size of 10 m by 10 m with a seeding rate of 100 kg/ha. At sowing, the recommended rate of DAP fertilizer was uniformly applied on the plots at each location. Other recommended cultural practices were also applied.

The National Variety Release Committee (NVRC) evaluated the varieties at field (Figure 2) conditions and based on their evaluation result, the variety *Ezo_ote*/ILRI_5527A was approved for cultivation in April 2022 to be utilized by various end-users.

2.6. Data collection

The plant height (PH cm) was measured using tape centimeter graduated meter for selected sample plants from ground to top of the plant at leaf end and panicle initiation begin. Dry matter yield (DMY t/ha) was computed by collecting 300 gram fresh sample from the four central rows at 50% flowering and dried under shade air to constant weight and using the formula: $DMY(t/ha) = DM\% \times FMY$ ($DM\% = \text{Dried sample} / \text{fresh sample} \times 100$).

Leaf to stem ratio (LSR) was calculated by dividing leaf dry matter to stem dry matter yield. Seed yield (SY t/ha): at harvest maturity, plants from the remaining four central rows were cut to 30 cm above ground level, seeds were threshed and dried in the shade to a constant weight to calculate the seed yield. Seeds were weighed in a sensitive balance and the yield converted to a per hectare base using the formula $SY (t/ha) = SYPP \times 0.3$, where SY is seed yield per hectare and SYPP is the seed yield for four rows.

Forage nutritional quality, in terms of ash, crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) concentration, was tested in the laboratory according to National Forage Testing Association (NFTA) procedures (Paine et al., 1999).

2.7. Data analysis

The data generated were statistically analyzed using the analysis of variance procedure and least significance difference, at the 5% probability level, of Genstat statistical software (version 16, VSN International LTD, UK) (Payne et al., 2015).

3. Results and Discussion

3.1. Agronomic and morphological characteristics

As presented in Table 2, the longest plant height was observed for the genotype ILRI_15153A (144.84 cm) followed by ILRI_15152A (142.25 cm). The height of standard check varieties SRCPX80AB2291 and SRCPX80AB2806 were 126.48 and 139.02 cm, respectively. The newly released variety *Ezo_ote* demonstrated the average plant height of 127.85 cm while the shortest plant in the experiment was ILRI_5499A with the height of 124.72

cm (Table 3). ILRI_15153 and SRCPX80AB2806 had higher leaf number per plant of 4.4 and 4.3 leaves per plant, respectively while the average leaf number of the newly released variety *Ezo_ote* was 3.9. There was no significant ($P>0.05$) variation observed for leaf to stem ratio of genotypes tested over location during 2018 and 2019 (Table 3). The new variety *Ezo_ote*(ILRI_5527A) (0.435), however, produced a higher leaf to stem ratio over the standard check SRCPX80AB2806 (0.375) and SRCPX80AB2291 (0.371)) with an advantage of 16.8% and 17.1%, respectively.

Table 2. Average plant height of oat varieties planted at four locations of Ethiopian regions during 2018 and 2019 cropping seasons

Genotype	Arba Minch	Areka	Bonga	Hawassa	Mean
ILRI_15152A	79.1 ^{bc}	133.83	176.8 ^{ab}	111 ^g	142.25 ^{ab}
ILRI_15153A	113.2 ^a	146	154.5 ^{bc}	135 ^b	144.84 ^a
ILRI_16101A	99.9 ^{ab}	155.67	186.2 ^a	115 ^f	132.45 ^{cd}
ILRI_5431A	117.25 ^a	149.5	160.4 ^{bc}	142 ^a	128.56 ^d
ILRI_5444A	66.45 ^c	132	168.1 ^{abc}	110 ^g	134 ^{bcd}
ILRI_5490A	119.95 ^a	135.17	146.1 ^c	106.3 ^h	132.91 ^{bcd}
ILRI_5499A	99.65 ^{ab}	128.33	174.4 ^{ab}	122.3 ^e	124.72 ^d
ILRI_5526A	98.2 ^{ab}	127.33	158.9 ^{bc}	130 ^c	126.32 ^d
ILRI_5527A (<i>Ezo_ote</i>)	78.6 ^{bc}	130.17	148.2 ^c	126 ^d	127.85 ^d
SRCPX80AB2291	94.6 ^{abc}	117.83	156.8 ^{bc}	117.3 ^f	126.48 ^d
SRCPX80AB2806	85.1 ^{bc}	145	175.7 ^{ab}	106 ^h	139.02 ^{abc}
Mean	95.63	136.439	164.19	120.09	132.67
CV%	25.5	9.7	8.9	6.5	8.8
LSD _{0.05}	39.8	NS	24.87	14.1	18.89

Different letters in a column are indicating significant ($P<0.05$) difference among genotypes, CV% coefficient of variation, LSD is least significant difference at 5% probability level.

The newly released variety of oats, *Ezo_ote*, is an annual herbaceous grass type dual purpose crop which can be characterized by its agronomic and morphological characteristics. The maximum plant height of *Ezo_ote* oat variety at 50% flowering, forage harvesting stage was 176.8 cm. The newly released variety was attained 85-92 days to flowering, the maximum days to forage harvesting (50% flowering) at 115 days while the standard checks SRCPX80AB2291 and SRCPX80AB2806 121 and 147 days after planting. The seed harvesting of newly released variety took 160 days while the checks 165 and 169 days, respectively. This indicates the newly released oat variety can be characterized as early maturing type when comparing to SRCPX80AB2806 and SRCPX80AB2296 varieties.

The white seed colored and long seed sized newly released variety exhibited a hundred seed weight of 39.33 gram which is higher than the hundred seed weight of SRCPX80AB2806 (30 gram) while comparable with the hundred seed weight of SRCPX80AB2296 (39.33 gram). The harvest index (0.17) of newly released variety was by far better than the harvest index of both checks. Panicle length and spikelet number of the newly released variety were superior over the check variety SRCPX80AB2806 but comparable with SRCPX80AB2296. The white colored new variety with easy threshing ability with stands lodging better than both checks. According to the lodging assessment at VVT, newly released variety *Ezo_ote* was exposed to lodging by 5% while SRCPX80AB2296 25% and SRCPX80AB2806 15% especially at Doyogena and Kemba.

Table 3. Average leaf number per plant (LNPP) and leaf to stem ratio (LSR) of oat varieties panted at four Locations of Ethiopian regions during 2018 and 2019 cropping seasons

Genotype	LNPP			LSR		
	2018	2019	Mean	2018	2019	Mean
ILRI_15152A	3.5	4.1	3.8 ^{abc}	0.26	1.99	1.13
ILRI_15153A	4.7	3.9	4.3 ^a	0.49	0.51	0.5
ILRI_16101A	3.1	3.9	3.5 ^{bc}	0.48	1.69	1.09
ILRI_5431A	3.7	3.6	3.6 ^{bc}	0.47	1.28	0.88
ILRI_5444A	4.9	3.3	4.1 ^{ab}	0.78	1.15	0.96
ILRI_5490A	4.3	4	4.1 ^{ab}	0.62	0.94	0.78
ILRI_5499A	3.7	3.9	3.8 ^{abc}	0.56	1.24	0.9
ILRI_5526A	3.3	4.3	3.8 ^{abc}	0.54	1.77	1.15
ILRI_5527A (<i>Ezo_ote</i>)	3.6	4.1	3.9 ^{abc}	0.57	1.37	0.97
SRCPX80AB2291(SC)	4	2.6	3.3 ^c	0.49	0.84	0.67
SRCPX80AB2806(SC)	4.3	4.4	4.4 ^a	0.37	1.26	0.81
Mean	3.9	3.8	3.9	0.51	1.28	0.89
CV%=14.1 LSD _{0.05} =0.64			CV%=48.3 LSD _{0.05} =NS			

Different letters in a column are indicating significant ($P < 0.05$) difference among genotypes, CV% coefficient of variation, LSD is least significant difference at 5% probability level.

Ezo_ote(ILRI_5527A) variety had higher number of tiller, leaf to stem ratio, plant height, and straw to grain ratio, dry matter, seed and crude protein yield. The variety was better resistant to yellow rust and septoria net blotch than standard checks (SRCPX80AB2806 and both check (103.7 and 80 g/kg DM) varieties. The variety was characterized by its low ash, NDF, ADF and ADL content when compared to both check varieties.

Table 4. Morpho-agronomic characteristics of *Ezo_ote*(ILRI_5527A) dual purpose oat variety comparing to two standard check varieties

Variable	Description		
Variety name	<i>Ezo_ote</i>(ILRI_5527A) (Acc#ILRI-5527)	SRCPX80AB2806 (Standard Check)	SRCPX80AB2291 (Standard Check)
Agronomic and morphological characteristics:			
Adaptation area	Mid to highlands of southern, south western, southeastern and other similar agro ecological zones of Ethiopia		
Altitude (meter above sea level)	1800-3000		
Rainfall (mm)	1200-2042		
Temperature (°C) Max/Min	23.11-26.28/13.98-15.57		
Seed rate (kg/ha)	100		
Planting date	Early to Mid-July depending on the moisture status of location		
Spacing (cm)	20 cm between rows for seeds drilled in the rows		
Fertilizer rate (kg/ha): P ₂ O ₅	23		
N	23 (½ at planting and ½ at tiller initiation stage)		
Days to flowering	85-92		
Days to forage harvesting	92-115	133-147	112-121
Days to seed harvesting	155-160	155-165	155-169
Plant height at forage harvest (cm)	85.07-175.73	113.23-154.53	79.07-176.8
Leaf to stem ratio	0.435	0.371	0.371
1000 seed weight (g)	39.33	30	39.33
Harvest index	0.17	0.12	0.11
Panicle length (cm)	24.67	24.07	24.93
Spikelet number	21.13	17.73	21.8
Seed color	White		
Straw to grain ratio	4.321	3.55	3.11
Thresh ability	Easy		
Lodging incidence	Moderately resistant		
Crop pest reaction (1-5):	Resistant to septoria net blotch and yellow rust		
Forage quality (g/kg DM)			
CP	117.6	103.7	80
Ash	47.9	48.2	51.5
NDF	470.1	526.1	548.7
ADF	318.5	389.7	386.5
ADL	85.7	100.9	98
Yield (t/ha)			
Forage dry matter	12.59	11.67	10.38
Seed	3.59	3.6	3.3
Straw	8.64	5.54	6.42
Crude Protein	1.45	1.21	0.83
Year of release	2022		
Breeder/maintainer	Arba Minch Agricultural Research Center/SARI		

The newly released variety was superior in terms of crude protein (117.6 g/kg DM) quality in gram per kilogram dry matter over

The newly released oat variety was adapted to mid to higher altitudes ranging from 1800-3000 meters above sea level with an annual rainfall ranging from 1200-2042 mm. *Ezo_ote*, new oat variety had good performance under nitosol and clay loam soil types. The new variety should be sown early to mid-July with a seeding rate of 100 kg ha⁻¹ at 25 cm row spacing. At planting, the application of the recommended rate of DAP and Urea (at planting and at tiller initiation stage) fertilizers enhances the establishment performance of oat variety. The agronomic and morphological characteristics of the released oat variety are presented in Table 4.

3.2. Yield performance in different environmental locations

3.2.1. Dry matter yield (DMY)

The newly released oat variety is a dual purpose which can be used for animal feed as well human food. Dry matter yield of the new variety and its standard checks were presented in Figure 2. *Ezo_ote* (ILRI_5527A) was produced a higher mean dry matter yield (12.59 t/ha) in six environments than SRCPX80AB2806 (11.67 t/ha) and SRCPX80AB2291 (10.38 t/ha) during the evaluation season. The higher dry matter yield was produced at Bonga (2019=19.5, 2018=13.78 t/ha) followed by Areka (2019=13.98, 2018=7.42 t/ha) and Arba Minch (2018=8.29, 2019=6.76 t/ha).

The average dry matter yield of oat varieties in testing environments presented in Table 5. The mean dry matter yield performance of oats varieties ranged from 10.38 to 14.05 t/ha with a mean of 11.62 t/ha across the test environments. The highest mean dry matter yield was recorded for IRLI_15153A followed by *Ezo_ote* (ILRI_5527A) and ILRI_5526A, while SRCPX80AB2291 and SRCPX80AB2806 gave the lowest dry matter yield across the environments. The rank of the varieties for dry matter yield was different across the test environments which are indicating the effect of genotype by environment interaction on dry matter yield performances of the oat varieties. Concerning the yield advantage of dry matter, *Ezo_ote*/ILRI_5527A, newly released variety, had a yield advantage of 10.54% and 24.28% over check varieties SRCPX80AB2806 and SRCPX80AB2291, respectively.

The current result on dry matter yield for newly released variety, *Ezo_ote* 12.59 t/ha, was by far better than Gadisa et al., (2023) who reported a combined dry matter yield performance range of 6.2 to 9 t/ha in Eastern Oromia but closely comparable with Gezahagn et al., (2021)

who reported an oat dry matter yield ranging from 11.5 to 15.6 t/ha in central highlands of Ethiopia. Hence, the performance of dry matter yield of oat genotypes was significantly affected by the genetic, environmental, and their interaction effects.

Table 5. Average dry matter yield of oat varieties across location over years

Genotypes	AM18	AM19	Ar18	Ar19	Bn18	Bn19	Genotype Mean
ILRI_15152A	6.578 ^d	7.19 ^{bc}	8.73	15.49	12.23 ^{cd}	22.11 ^a	12.05
ILRI_15153A	12.565 ^a	9.469 ^{ab}	8.10	15.00	15.64 ^{bc}	23.55 ^a	14.05
ILRI_16101A	9.895 ^{abc}	6.409 ^{bc}	7.27	12.48	11.21 ^d	19.15 ^{abcd}	11.07
ILRI_5431A	7.913 ^{bcd}	7 ^b	6.93	13.60	12.81 ^{cd}	17.05 ^{cd}	10.44
ILRI_5444A	6.471 ^d	6 ^{bcd}	7.60	15.83	11.83 ^d	21.7 ^{ab}	11.37
ILRI_5490A	6.584 ^d	6.34 ^{bc}	4.37	11.40	11.53 ^d	22.65 ^a	10.48
ILRI_5499A	7.757 ^{bcd}	6.246 ^{bc}	6.57	12.94	17.06 ^b	17.27 ^{bcd}	11.31
ILRI_5526A	8.805 ^{bcd}	11.425 ^a	8.70	16.91	14.14 ^{bcd}	14.54 ^d	12.42
ILRI_5527A (<i>Ezo_ote</i>)	7.586 ^{bcd}	7.897 ^{abc}	8.13	13.16	22.07 ^a	16.69 ^{cd}	12.59
SRCPX80AB2291	7.038 ^{cd}	2.138 ^d	6.40	13.78	12.29 ^{cd}	20.64 ^{abc}	10.38
SRCPX80AB2806	9.983 ^{ab}	8.084 ^{abc}	8.83	13.22	10.73 ^d	19.15 ^{abcd}	11.67
Environment mean	8.29	6.76	7.42	13.98	13.78	19.50	11.62
LSD _{0.05}	2.877	3.91	NS	NS	3.80	4.61	
CV%	20.4	18.3	23.30	19.60	16.20	13.90	

AM= Arba Minch, Ar=Areka, Bn= Bonga, 18 and 19 are 2018 and 2019; different letters in a column are indicating significant ($P<0.05$) difference among genotypes, CV% coefficient of variation, LSD is least significant difference at 5% probability level.

3.2.2. Seed yield (SY)

The average seed yield and its advantage of newly released oat variety, *Ezo_ote*, presented in Table 6 below. The seed yield performance of oat genotypes varied significantly ($P<0.05$). The seed yield variation among oat genotypes was ranging from 2.61 to 3.87 t/ha in the present study. The highest seed yield was obtained from the genotype ILRI_15153A followed by ILRI_15152 which was not significantly varied with newly released variety and the check SRCPX80AB2806. The lowest seed yield was for ILRI_16101A genotype in the present evaluation.

The average seed yield of 3.6 t/ha produced by *Ezo_ote*/ILRI_5527A was superior over the check variety SRCPX80AB2291 with a yield advantage of 9%. However, the seed yield of newly released variety, *Ezo_ote*, was closely similar and comparable with another check SRCPX80AB2806 in the present experiment. The previously reported seed yield of check varieties SRCPX80AB2291 2.76 t/ha and SRCPX80AB2806 3.21 t/ha (Gezahagn et al., 2021) was lower than the performance of current evaluation for each 3.29 t/ha and 3.6 t/ha,

respectively. This may be due to the environment advantage for the high yielding. Beyene et al., (2015) reported high variation of seed yield among different oats varieties. The seed yield of 3.64 t/ha for oats which has been reported by (Singh et al., 2018) was closely comparable with the seed yield of recently released variety. The new variety was also recommended for higher seed yield and optimum dry matter in the preliminary yield trial (Atumo & Kalsa, 2020). Therefore, the performance of seed yield of oats was significantly affected by the genetic factors, environmental factors, and interaction of genotype and environment.

3.2.3. Crude Protein Yield (CPY)

The average crude protein yield and its advantage over check varieties is presented in Table 6. The crude protein yield of oats genotypes was varied significantly ($P < 0.05$) among genotypes.

Table 6. Average seed yield (SY T/Ha), crude protein yield (CPY T/Ha) and yield advantages of newly released oat variety (*Ezo_ote*) over checks in the evaluation

Genotypes	SY t/ha	Yield advantage over checks		CPY t/ha	Yield advantage over checks	
		SRCPX80-AB2806 (%)	SRCPX80-AB2291 (%)		SRCPX80-AB2806 (%)	SRCPX80-AB2291 (%)
ILRI_15152A	3.85 ^a	7	17	1.21 ^b	0	46
ILRI_15153A	3.87 ^a	7	18	1.07 ^c	0	29
ILRI_16101A	2.61 ^c	0	0	1.06 ^c	0	28
ILRI_5431A	3.19 ^b	0	0	0.89 ^d	0	7
ILRI_5444A	3.28 ^b	0	0	1.15 ^c	0	39
ILRI_5490A	3.61 ^{ab}	0	10	1.03 ^c	0	24
ILRI_5499A	3.16 ^b	0	0	1.13 ^c	0	36
ILRI_5526A	3.10 ^b	0	0	1.29 ^b	7	55
ILRI_5527A (<i>Ezo_ote</i>)	3.59 ^{ab}	0	9	1.48 ^a	22	78
SRCPX80AB2291	3.29 ^b	0	0	0.83 ^d	0	0
SRCPX80AB2806	3.60 ^{ab}	0	10	1.21 ^b	0	46
Mean	3.38			1.12		
LSD0.05	0.5	-	-	0.15	-	-
CV%	12.6	-	-	11.2	-	-

Different letters in a column are indicating significant ($P < 0.05$) difference among genotypes, CV% coefficient of variation, LSD is least significant difference at 5% probability level.

The crude protein yield variation among oats genotypes was ranging from the lowest yield of 0.83 t/ha for a check variety SRCPX80AB2291 to 1.48 t/ha for the newly released oats variety *Ezo_ote*. *Ezo_ote*/ILRI_5527A variety gave higher mean crude protein yield of 1.48 t/ha than

SRCPX80AB2806 (1.21 t/ha) and SRCPX80AB2291 (0.83 t/ha). The advantage of crude protein yield of *Ezo_ote* was 22% over SRCPX80AB2806 while 78% over SRCPX80AB2291 check variety. This may indicate approving the newly released variety to be registered and released in the tested locations and similar ecologies would have an advantage of growing calves, rearing milking cows, oxen and other livestock species.

3.3. Reaction to major diseases

The released *Ezo_ote* variety was tested for diseases and pests reaction starting from the initial stage of evaluation to verification stage and found to be resistant to major diseases and pests which can affect the varieties as presented in Figure 3. The diseases and pest effects on the performance of oats varieties were recorded as 0-10% resistant, 11-30% moderately resistant, 31-60% moderately susceptible, and 61-100% susceptible. It was scored using the procedure of Peterson et al., (1948) modified cob rating scale for yellow rust by a diagrammatic scale for estimating rust intensity on leaves and stems of cereals.

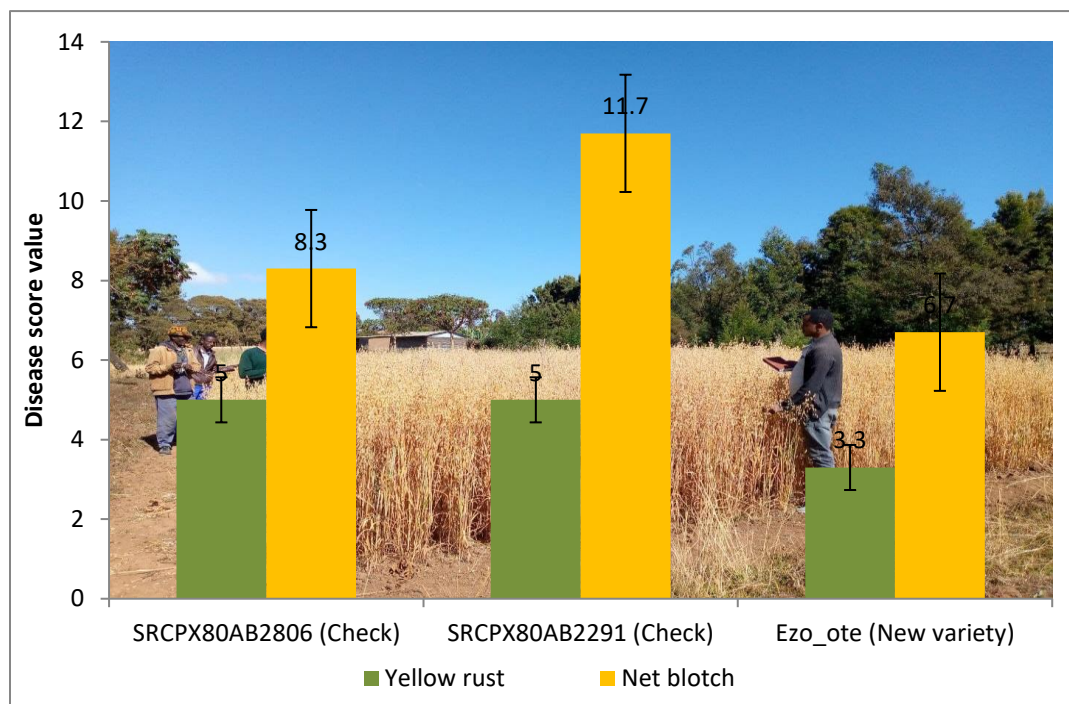


Figure 3. Yellow rust and septoria net blotch diseases reaction of *Ezo_ote* (ILRI_5527A) variety comparing with standard checks during variety evaluation; scoring values 0-10% resistant, 11-30% moderately resistant, 31-60% moderately susceptible, and 61-100% susceptible

Yellow rust and septoria net blotch were the important diseases occurred during the variety evaluation and verification process of the varieties. *Ezo_ote*(ILRI_5527A) was found to be resistant to yellow rust diseases of oats when compared to both check varieties in the

evaluation. The variety *Ezo_ote*(ILRI_5527A) was also resistant to Septoria net blotch disease compared to standard checks in the variety evaluation trial. In similar year (2018) with the variety evaluation, the experimental sites especially Chenchu and Bonke area were reported for yellow rust and stem rust stress tempting the production of wheat crops (Mengesha, 2020). The resistance reaction of newly released oat variety could be integrated with other diseases and pest management strategies for better results. Therefore, the released oat variety could be superior in tolerance to major diseases and pests when compared to both standard check varieties.

3.4. Forage quality analysis

The concentration in gram per kilogram dry matter of forage quality parameters of the new variety (*Ezo_ote*) and standard checks in terms of crude protein, acid detergent fiber, neutral detergent fiber, acid detergent lignin and ash is presented Table 7. New variety demonstrated higher concentration of crude protein with lower concentration of neutral detergent fiber, acid detergent fiber and lignin than both standard check varieties in the trial.

As presented in Table 7, the newly released variety, *Ezo_ote* had higher CP, but lower ash and fiber contents than the check varieties. However, the variation in ash content among oats genotypes was not significant ($P>0.05$), the ash composition of *Ezo_ote* was as lowest as 47.9 g/kg DM. The released oat variety *Ezo_ote* gave the highest CP concentration of 117.6 g/kg DM. The lowest NDF, ADF and ADL composition was recorded for *Ezo_ote*, newly released variety, with the value of 470.1 g/kg DM, 318 g/kg DM and 85.7 g/kg DM, respectively, when compared to check varieties and other genotypes in the evaluation. The crude protein advantage of newly released oat variety, *Ezo_ote*, over check varieties SRCPX80AB2291 and SRCPX80AB2806 were 47% and 13.4%, respectively.

Crude protein (CP) value of *Ezo_ote* variety was 117.6 g/kg DM. This value is higher for oat varieties that (Gadisa et al., 2023) reported CP value ranging from 96 to 102.1 with a mean of 99.3 g/kg DM for 15 genotypes, (Gezahagn et al., 2021) 69 to 81 with a mean of 77 g/kg DM for 15 genotypes. Moreover, the recently released variety, *Ezo_ote*, was superior on crude protein composition over the check varieties at present evaluation and the value at time of releasing for the checks (EAA, 2021). Average value of Acid detergent fiber (ADF) composition of *Ezo_ote* variety was 318.5 g/kg DM. This value is lower than the result of (Gadisa et al., 2023) who reported the ADF value of oat genotypes ranging from 628 to 686 g/kg DM with the average composition value of 651.7 g/kg DM. When compared to the present ADF composition value of

Ezo_ote variety, another scholar (Gezahagn et al., 2021) also reported the higher ADF composition ranging from 454 to 520 g/kg DM with the mean value of 485 g/kg DM. The present ADF value 318.5 g/kg DM concurs with the ADF value 313 to 383 g/kg DM reported at variety releasing of Bonsa and Bona-bas oats variety for Bale highlands of Ethiopia (Abate & Wegi, 2011).

Table 7. Average chemical composition (g/kg DM) of oat varieties at different locations 2018-2019

Genotype	ADF	ADL	Ash	CP	DM	NDF
ILRI_15152A	415.5 ^a	104.6	44.8	100.1 ^b	966.7	559.6 ^a
ILRI_15153A	398.8 ^{ab}	102.7	42.5	76.1 ^c	940	526.1 ^{abc}
ILRI_16101A	361.4 ^{abc}	87.7	51.9	96.1 ^b	963.3	513.3 ^{abcd}
ILRI_5431A	344.7 ^{bcd}	84.2	51.9	84.8 ^c	960	484.1 ^{cd}
ILRI_5444A	369.6 ^{ab}	91.6	58.2	101.4 ^b	973.3	505.9 ^{abcd}
ILRI_5490A	365.2 ^{abc}	96.2	48.1	98.1 ^b	970	492.3 ^{bcd}
ILRI_5499A	348.0 ^{bcd}	87.9	51.9	99.6 ^b	966.7	472.0 ^{cd}
ILRI_5526A	300.5 ^d	79.5	48.8	104.1 ^b	956.7	455.8 ^d
ILRI_5527A (<i>Ezo_ote</i>)	318.5 ^{cd}	85.7	47.9	117.6 ^a	973.3	470.1 ^{cd}
SRCPX80AB2291	386.5 ^{ab}	98	51.5	80.0 ^c	970	548.7 ^{ab}
SRCPX80AB2806	389.7 ^{ab}	100.9	48.2	103.7 ^b	966.7	526.1 ^{abc}
Mean	365	92.6	49.6	96.5	964.2	504.9
CV%	12.5	15.7	21.1	11.2	2	9.8
LSD _{0.05}	3.8	NS	NS	0.92	NS	4.2

4. Conclusion

The results of the present study have confirmed that *Ezo_ote*(ILRI_5527A) variety demonstrated a high dry matter, seed and crude protein yield, resistant to yellow rust and septoria net blotch diseases. Moreover, the variety has lower fiber content such as neutral detergent fiber, acid detergent fiber, acid detergent lignin; early flowering, higher leaf to stem ratio, greater number of tillers per plant, harvest index and straw grain ratio. Generally, the variety has traits preferred by farmers as confirmed by their positive feedback during the evaluation and verification trials. As the variety has been approved by the National Variety Release Committee (NVRC), it is possible to recommend the newly released variety for fodder and grain production. Based on the crude protein and dry matter production, the variety could be promoted for calves, milking cows, draft animals and other livestock species feed material. The seed yield is also optimum and recommended for grain production too. Hence, it is necessary to promote the newly released variety, *Ezo_ote*, in mid and highlands of south, southwestern and south eastern

Ethiopia and similar agro-ecologies. Farmers, investors, government and non-government organizations, researchers, universities and other concerned entities could use the newly released variety, *Ezo_ote*, for their intended purposes in the tested and similar environments in Ethiopia and elsewhere.

Conflict of Interest

The author(s) did not disclose any potential conflicts of interest

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Research Articles

The Assuan labeo or Labeo horei Heckel (Pisces: Cyprinidae) in Lake Chamo, Ethiopia: Reproductive biology and condition factor

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Abstract

The Labeo horei (Heckel, 1847), the Assuan labeo, is an ecologically and economically important fish of Lake Chamo; thus, reproductive biology and condition factors of the fish were investigated in order to provide information essential for appropriate stock exploitation and sustainable management. Fish specimens were collected monthly from sampling stations at Lake Chamo between July 2022 and January 2023. A total of 462 specimens were collected for analysis. The mean condition factor was 1.11, which indicates a good state of wellbeing in the habitat during the period of study. The overall male to female sex ratio (1: 0.83) did not deviate substantially from the anticipated value of 1:1 ($x^2 = 3.82$, $P < 0.01$). The fecundity of *L. horei* ranged from 200,000 to 1000,000 eggs and was found in mature ovaries (mean 261,045.8 eggs). These results confirm the suitability of Lake Chamo for the survival of *L. horei*. There is, however, a need for a systematic closed fishing regime to be employed in order to make way for sustainable growth of *L. horei* fisheries in the lake Chamo as the fish candidate for future aquaculture development.

Keywords: Breeding season; Condition factor; Fecundity; Fishery; Labeo horei; Lake Chamo

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1. Introduction

The Assuan labeo, or *Labeo horei* (Heckel, 1847), is found across Northern Kenya and the majority of the Ethiopian drainage basin (Elias et al., 2013). It is extensively dispersed in Ethiopia's Rift Valley basin, Abay basin, and Baro-Akobo basin (Awoke, 2015). It is one of Ethiopia's economically important fish species (LFDP, 1997; Zerihun et al., 2006). According to LFDP (1997), the yearly production of *L. horei* from Ethiopia's inland water bodies is estimated to be around 365 tons per year. Fish are less readily available in local markets as a result of the

reduction of fish species brought on by overfishing and parasite infection (Zerihun et al., 2006; Elias et al., 2013).

The most frequent *Labeobarbus* species in freshwater, *Labeo horei*, possesses morphological and physiological characteristics that set it apart from other members of the species (Nagelkerke, 1997). The length-weight relationship is one of the most important biological tools for controlling fisheries. It is used to calculate the average weight of a fish at a certain length (Lawson et al., 2013). It also provides important data for aquatic ecosystem modeling, such as the influence of environmental variables, habitat changes, species interactions, and food availability (Dan-Kishiya, 2013).

As a result, the length-weight relationship of fish in various environmental conditions should be identified. One of the most commonly utilized analyses in fisheries is the length-weight relationship. Fish length-weight data are useful for examining the length and age structures, population dynamics, growth, mortality rate, and fish well-being (Temesgen, 2017). They are also key instruments for accessing data on length frequency distribution, fish welfare, stock evaluation, and fish population management (Abowei et al., 2009).

Numerous aspects of the biology and ecology of economically significant fish species have been studied in Lake Chamo (Hailu & Seyoum, 2001; Elias et al., 2003; Elias et al., 2012; Hailu, 2013). Nevertheless, there is a scarcity of information on biometric traits such as length-weight relationships and condition factors. This necessitates an investigation into the biometric characteristics (sex ratio, breeding season, and fecundity), length-weight relationship, and condition factor of *L. horei* from Lake Chamo, with the aim of providing scientific information for appropriate stock exploitation and management in the wild and underculture, given that *L. horei* is one of the most commercially important fish in Lake Chamo's catches, Southern Ethiopia, Ethiopia.

2. Materials and Methods

2.1. Description of the study area

This study was carried out in Lake Chamo, Arba Minch, Ethiopia (Figure 1). Lake Chamo, located in (Lat.: 5°42' - 5°48' N; Long: 36°30' - 38°30' E), is located at an elevation of 1108 m, about 518 kilometres south of Addis Ababa. The lake has a surface area of 551 km² and is the second largest among the rift valley lakes and the third largest in the country. Lake Chamo

had a maximum depth of 20 meters according to older data (Amha & Wood, 1982); however, Elizabeth (1996) claimed a maximum depth of 13 meters.

As the lake has retreated by nearly half a kilometer over the past two decades, Beadle (1981). Which significantly reduces the surface area, the mean depth of the lake may have altered. The Kulfo River, which enters from the north, and two less significant rivers, Sile and Sego, which enter from the west, are the main sources of water for Lake Chamo. In spite of the fact that it now lacks a visible surface outflow (Yirga et al., 2000).

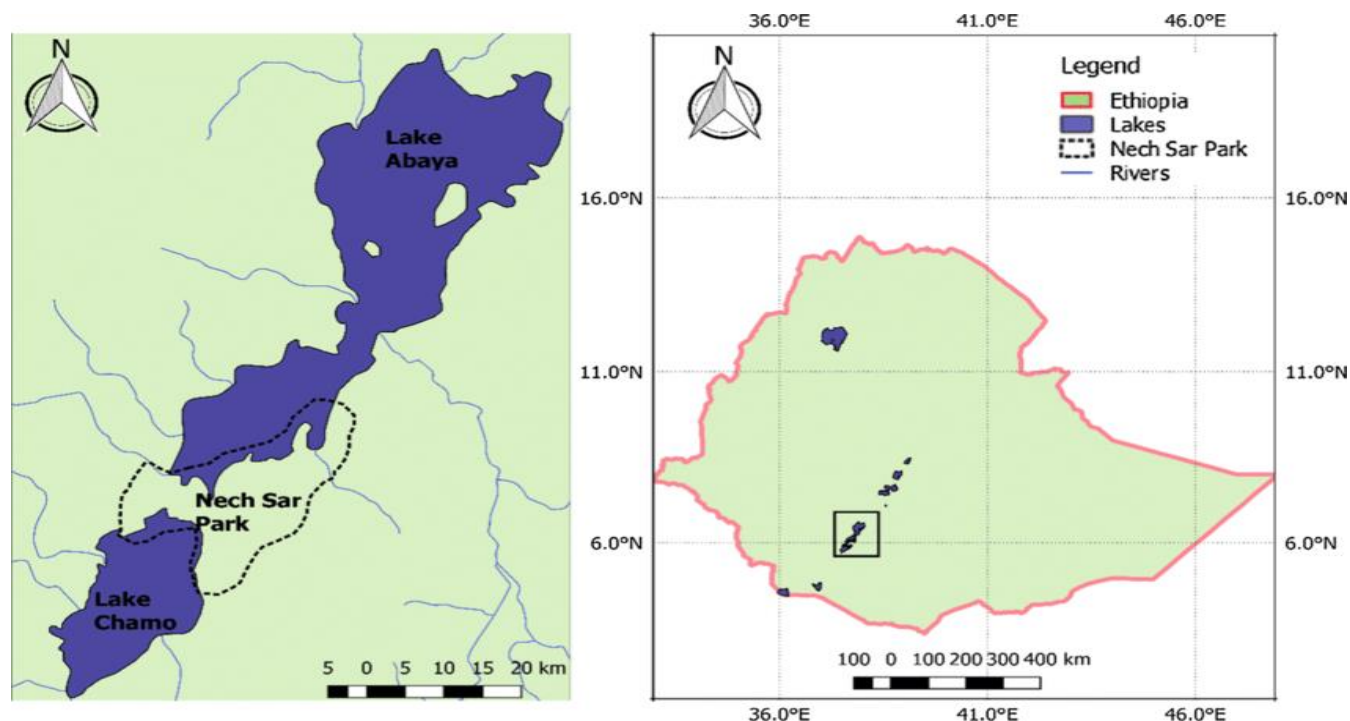


Figure 1. Map of Lake Chamo, the research area

2.2. Sampling of fish and measurement

Monthly fish samples were taken from the lake and brought to the Fishery Laboratory of Hawassa University from July 2022 to January 2023. The landing points at Letto (1, 2, 3, 4, and 5) were used to acquire fish for commercial purposes.

The mesh size used in commercial gill nets ranges from 6 to 8 cm. Gill nets were deployed late in the day and removed the next morning. To the closest centimeter and gram, the TL and TW of each fish were measured immediately following being captured. Each fish was then dissected, and the gut contents were transferred to a labeled plastic bottle containing a 5% formalin solution. Those fish with no gut content were noted as empty gut. The preserved gut contents were delivered to the laboratory. According to a five-point maturity scale (immature,

maturing, ripening, ripe, and spent) that was used for this purpose (Holden & Raitt, 1974), the gonads of each fish were removed, weighed to the nearest 0.01 gram, and their maturity stages were visually rated and recorded. The ovaries were split longitudinally and turned inside out to ensure the penetration of the preservative before they were stored in labeled jars. At the end, the ripe ovaries were preserved in a 5% formalin solution for fecundity estimation (Bagenal, 1978).

2.3. Reproductive biology

2.3.1. Sex-ratio

The sex-ratio (female: male) was computed for each month, for the various length classes, and for the entire sample. As in Demeke (1994) monthly samples, different size classes, and the entire sample were tested to see if the sex ratio varied from one to one using the chi-square test.

2.3.2. Breeding season

The monthly frequency of fish with mature gonads and the calculation of the gonado somatic index (GSI) were used to identify the breeding season of *L. horei*. The GSI for each fish was calculated using the following formula (Eq. 1):

$$GSI = \frac{GW}{TW} \times 100 \quad (1)$$

Where; GSI stands for the gonado somatic index. GW stands for gonad weight in grams, TW stands for "total weight" in grams.

2.3.3. Fecundity

Gravimetrically, the fecundity of ripe gonads preserved in 5% formalin solution was evaluated (Bagenal, 1978). To calculate fecundity, the preservative was replaced with water, and the eggs were washed repeatedly while the supernatant was decanted. The fecundity estimate was then produced by weighing the complete egg sample and taking three sub-samples of each egg sample, all of which were dried in the same manner. The eggs were weighed and counted using a balance. The eggs were counted and the average weight was estimated after they were extracted from various sections of the ovary. Extrapolation from the estimated mean resulted in the total number of eggs per ovary. The sum was calculated using the following ratio (Eq. 2):

$$N/n = W/w \quad (2)$$

Where; N = denotes the unknown total number of eggs, n = the total number of eggs counted in three subsamples, W = Total egg weight (g), w = the weight of the three subsamples on average (g)

2.3.4. Fulton's condition factor

Fulton's condition factor (FCF) is an essential growth measure that determines the fish's well-being (Bagenal, 1978). The mean FCF for each month was calculated by sex. ANOVA was utilized to discover significant differences by sex and month of capture. It was determined using the following formula (Eq. 3):

$$FCF = \frac{TW}{TL^3} \times 100 \quad (3)$$

Where; FCF stands for Fulton condition factors, TW is the total weight of the fish (g), and TL is the total length of the fish (cm).

2.4. Data analysis

Data was collected and entered into SPSS and Microsoft Office Excel 2007 for Windows version 19 in order to evaluate the breeding season, sex ratio, length-weight connections, and fecundity. Ultimately, a table, scatter plot (x, y), and graph were created from the results. One-way ANOVA and chi-square tests were among the statistical tests used to ascertain the significance between the variables.

3. Results

3.1. The Fulton's condition factor

Fulton's condition factor (k) gives information on the state of the fish in relation to general well-being. According to Fulton (1904), $k < 1$ means that the fish are in poor condition and $k > 1$ means the fish is in healthy condition. There was no difference in the results between the sexes, and Fulton condition factors were both equal at 1.11 ± 0.01 (2, $P > 0.01$).

Additionally, *L. horei* overall condition factor result was 1.11 ± 0.01 . This implies that the fish were in good health condition.

3.2. Reproduction

3.2.1. Sex ratio

About 252 (54.5%) of the 462 *L. horei* fish samples were males, while the remaining 210 (45.5%) were females. The total male to female sex ratio (1:0.83) did not deviate substantially from the anticipated value of 1:1 ($\chi^2 = 3.82$, $P < 0.01$) (Table 3). There was no significant variation in sex ratio in all size class except in size class between was highly significant (i.e., 35 - 39.9; $\chi^2 = 9.31$, $P < 0.01$) (Table 1).

Table 1. The number of female and male *L. horei* collected in Lake Chamo between July 2022 and January 2023, as well as their sex ratio (Male: Female)

Size class (cm)	Males	Females	Sex ratio (M:F)	X ²
30.0-34.9	10	0	-	-
35.0-39.9	12	1	1: 0.08	9.31**
40.0-44.9	52	36	1: 0.69	2.91
45.0-49.9	134	106	1: 0.79	3.27
50.0-54.9	40	57	1: 1.43	2.98
55.0-59.9	4	10	1: 2.50	2.57
Total	252	210	1: 0.83	3.82

** = Highly significant at 1% level

3.2.2. Breeding season

Despite the fact that some ripe fish were taken throughout the year, the proportion of fish with ripe gonads was highest between September and November, when 67.7%–72.0% of males and 23.5%–100% of females had ripe gonads (Figure 2).

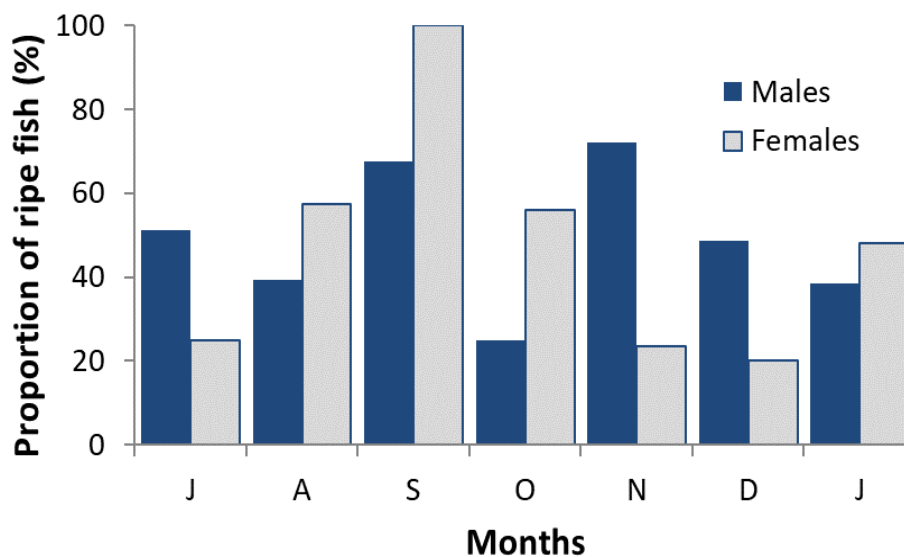


Figure 2. Proportion of ripe *L. horei* in Lake Chamo in 2022

Between December and July the proportion of fish with mature gonads was somewhat low, with 48.6%–51.1% of males and October and January 48%–56% of females having ripe gonads (Figure 2). And also during the months of August and October, the proportions of fish with ripe gonads were likewise low, with 25–39.3% of males, whereas in December and November, 20%–23.3% of females had ripe gonads (Figure 2). As a result, *L. horei* Lake Chamo breeds vigorously from September and November, with relatively small breeding activity at other periods of the year.

3.2.3. Fecundity

Only 107 of the 462 fish that were captured had mature ovaries in the females. Between 200,000 and 1,000,000 eggs were found in mature ovaries, with a mean of 261,045.8.

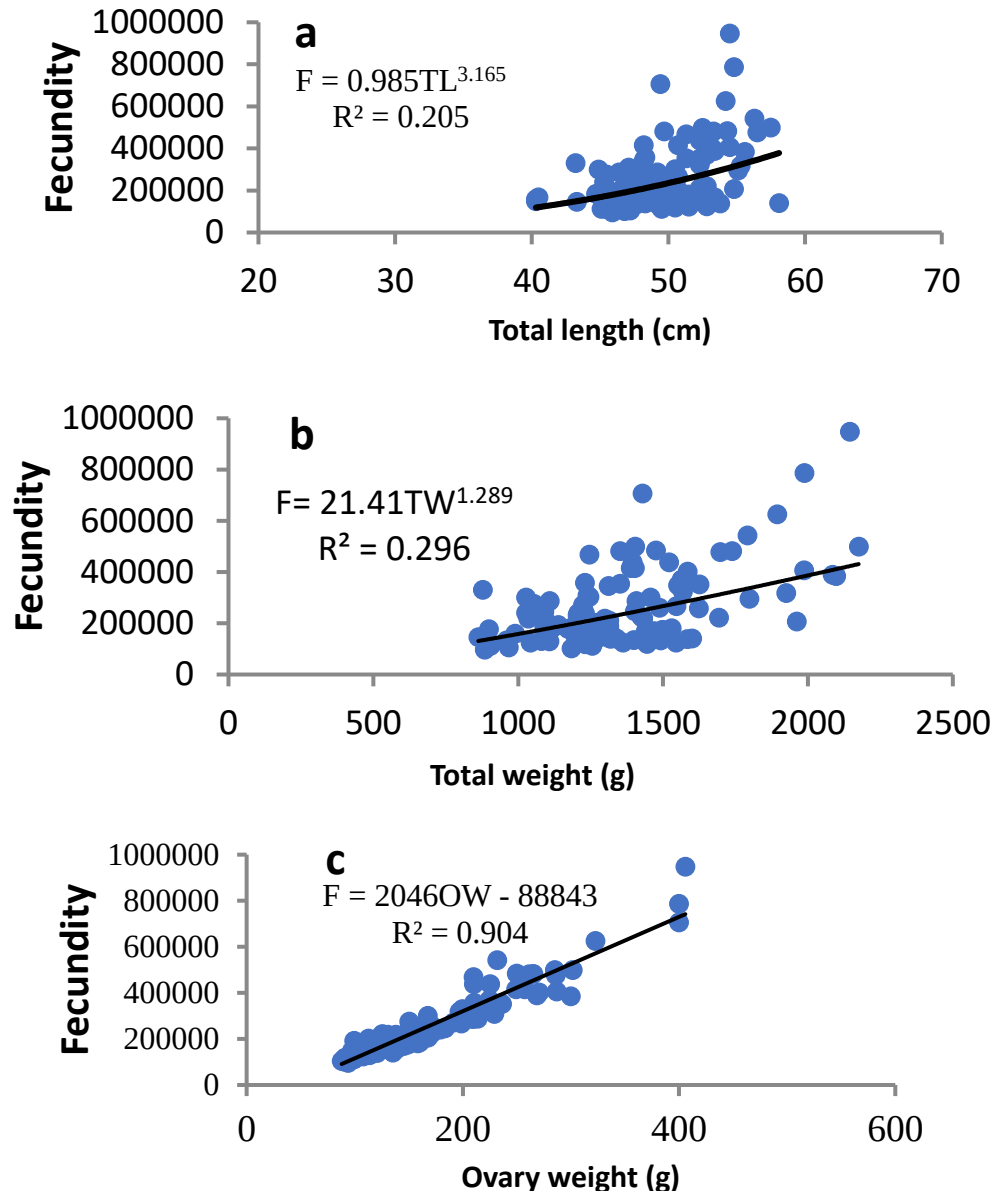


Figure 3. The relationship between fecundity and total length (a) fecundity and total weight (b) and fecundity and ovary weight of *L. horei* in Lake Chamo

Between 973 and 2875 eggs were present per gram of preserved wet weight of ovary, with 1464.4 being the average. In a fish that measured 45.9 TL and weighed 884 g, the lowest fecundity was 96511. A fish with a TL of 54.5 cm and a TW of 2145 g had the maximum fecundity of eggs, 947543 with a mean of 318580.8. In contrast, the curved correlations between

F and TL and TW were slightly curvilinear (Figures 3a and 3b), whereas the relationship between F and OW was linear (straight) (Figure 3c).

4. Discussion

4.1. The Fulton's condition factor

Fulton's condition factor (k) gives information on the state of the fish in relation to general well-being. According to Fulton (1904), k means that the fish are in poor condition, and $k > 1$ means the fish is in healthy condition. According to Dadebo *et al.* (2003) and Ogamba *et al.* (2014), the condition factor is used to measure the overall welfare of fish in their environment and that at a given length, larger fish have a better condition than lighter fish. When the condition factor is close to or equal to one, it portrays a fish's overall well-being (Abobi, 2015; Nazek *et al.*, 2018).

The mean condition factor observed in this study was more than one (i.e., 1.11), indicating that the fish in the lake were physiologically stable over the study period. In line with this, the average Fulton's condition factor found in this study (1.11) was in agreement with Fulton's (1904), if $k > 1$, the fish are in poor condition, and if $k > 1$, the fish exhibit good condition, similar to the results from Lake Ziway (1.73) that were previously reported. Lake Langeno (2016), Lemma (1.33), Shewit *et al.* (2012) in the Infranz River (1.27), Shewit *et al.* (2013) in the Geba and Sor Rivers (1.21), and Mathewos *et al.* (2018) in the Arno-Garno River (1.3) are a few others. Genanaw (2006) in the Beles and Sanja Rivers (1.1, 1.05), Zeleke (2007), Simagne *et al.* (2017) in the Angereb River (1.14), Shewit *et al.* (2014) in the Aveya River (1.18), and Genanaw (2007). This suggests that *L. horei* in Lake Chamo has a good body condition in comparison to the above water bodies.

4.2. Reproduction

4.2.1. Sex ratio

The male-to-female ratio of *L. horei* did not deviate from the predicted 1:1. In most circumstances, such sex ratio variation is uncommon in fish. Fecundity success is highly dependent on sex ratio, and bias on either sex can create behavioral, biochemical, and physiological changes in fish, which may influence reproduction success (Manal *et al.*, 2017; Maskill *et al.*, 2017). In the size group between 35.0 and 39.9 ($\chi^2 = 9.31$, $P < 0.01$), there was also a statistically significant fluctuation in sex ratios. All other size groups did not show any significant difference.

Generally, males were more numerous than females. A high male-to-female ratio might cause stress due to competition during pursuing, limiting spawning and decreasing fertilization success (Maskill et al., 2017). Additionally, Gizachew *et al.* (2015) reported a male preponderance in some of the Lake Tana tributary rivers. According to the reports of Shewit *et al.* (2012), Dereje (2014) in Lake Tana and Awoke *et al.* (2015) in the Blue Nile River, female predominance is in contradiction to the findings of the current study. The aforementioned authors claimed that the majority of females were likely due to the spawning behaviors of the fish species, in which females may spend more time in the breeding locations than males. Various authors (Shewit et al., 2014; Tadlo et al., 2015; Simagnew et al., 2017; Agumassie, 2018) claim that, there is also no discernible difference in the species' sex ratio across different water bodies in Ethiopia.

L. horei breeds in Lake Chamo throughout the dry seasons of the year, unlike other Ethiopian lakes. Mathewos et al. (2018), Shewit *et al.* (2012) and Gizachew *et al.* (2015) all noted that *L. horei* breeds during wet seasons (Elias et al., 2003). Multiple spawning over a long season has significant benefits in aquaculture because it offers a regular supply of high-quality larvae (Dorostghoal et al., 2009) and *L. horei* reproductive behavior makes it an ideal choice for aquaculture.

4.2.2. Fecundity

Fecundity varied throughout years, months, and zones; this variation may be related to variations in fish size and food availability (Inyang and Ezenwaji, 2004). Fish may move from inter-confluences to confluences for spawning, particularly during floods during the rainy season, as fecundity is higher in confluences than in inter-confluences. The correlations between fecundity and fish sizes or gonad mass recorded for *L. horei* are also noted for the fish species in a natural West African lake by Inyang and Ezenwaji (2004).

The positive correlations between fecundity and length ($r^2 = 0.21$) and fecundity and somatic mass ($r^2 = 0.30$) were recorded for *Labeo horei* ($r^2 = 0.90$). However, these values were higher than those recorded for *Labeo coubie* ($r^2 = 0.18, 0.10$, and 0.80 , respectively) (Ikpi and Okey, 2010). The coefficient of determination for the correlation between fecundity and gonad mass ($r^2 = 0.90$) for *L. horei* is greater than the values obtained with fish size.

It is evident that the gonad weight has a stronger correlation with reproductive ability than fish size. These interactions allow fish species to develop quickly and reproduce prolifically

(Demska-Zakes and Dlugosz, 1995) traits that are crucial for aquaculture species. Similar findings were observed for other cyprinids like *Garra rufa* (Abedi, 2011), *Barbus holotaenia* (Mutambue, 1996), and *Labeo parvus* ($r^2 = 0.87$) (Montchowui et al., 2011).

5. Conclusions

Studies on the reproductive biology and condition factor have practical significance for the *L. horei* fishery. The condition factor of *L. horei* indicates the fish are in good health condition. Potential implications for population dynamics are indicated by the sex ratio. Breeding predominantly occurred during the dry seasons, with fecundity exhibiting variation across years, months, and capture zones, correlating closely with gonad mass. These biological traits underscore *L. horei*'s suitability for aquaculture endeavors. Expanding upon these findings, continuous research efforts are crucial to enhance our understanding of *L. horei*'s biology and its ability to adapt to evolving ecological conditions. Establishing robust monitoring systems for fishery resources, particularly in high-potential water bodies like Lake Chamo, is crucial. Consequently, the implementation of regulatory measures is necessary to ensure the sustainable management of *L. horei* fisheries. During breeding seasons, prohibiting shore fishing activities can help protect breeding stocks, while specifying gear requirements, such as minimum mesh sizes, is essential to facilitate the escape of mature individuals and support recruitment processes. Integration of these management strategies is essential to promote the sustainable utilization of *L. horei* resources while conserving ecological balance.

Acknowledgment

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Conflict of Interest

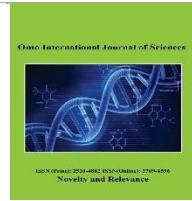
The authors declare that they have no competing interests.

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Research Article

Ethiopian perspectives and scientific explanations of the sun halo phenomenon on April 7, 2022
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Abstract

The purpose of this study was to analyze the many interpretations and reactions to the sun halo phenomenon reported in Ethiopia on April 7, 2022, with a particular focus on religious perspectives and scientific analysis. The diameter of the sun halo was measured to be 0.092 km, indicating the peculiarity of this atmospheric occurrence. A study among various religious leaders and community members revealed that 80% of respondents considered the phenomenon to require special prayers or religious rites, suggesting a significant tendency towards attributing spiritual significance. Additionally, 14% of respondents expressed curiosity about the event, indicating a normal human reaction to unusual or incomprehensible situations. Meanwhile, 3% of responders mentioned ceremonial offerings or no specific activities to the sun halo. From a technical aspect, picture analysis of the sun halo revealed an initial pixel count of 108,584 with a standard deviation of 43,265 and a noise standard deviation of 0.0962994, resulting in a signal-to-noise ratio (SNR) of 33.744. This study underlines the clarity and prominence of the sun halo in the obtained image. Furthermore, the study analyzed the relationship between the sun halo and atmospheric conditions, revealing a correlation coefficient of 0.49 on Day 7, coinciding with occasional cloud cover and atmospheric disturbances. The correlation coefficient slightly reduced to 0.48 on Day 8, when the sky was clear. These findings show a probable relationship between the presence of atmospheric disturbances and the appearance of the sun halo, offering a detailed explanation of this remarkable natural phenomenon. To understand the underlying atmospheric dynamics and probable seasonal trends, future studies should concentrate on a more thorough analysis of sun halos, combining a larger dataset of occurrences across diverse geographical regions and climatic conditions. Further research could investigate the psychological and cultural effects of celestial phenomena, such as sun halos, on various cultures, providing deeper insight into how these occurrences influence cultural norms and belief systems.

Keywords: Halo; Image; People thought; Scientific; Sun

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1. Introduction

A halo is an optical phenomenon that occurs when light, typically from the sun or moon, interacts with ice crystals in the atmosphere (Archenhold, 1994). Halos can take on a variety of shapes, including colored or white rings, arcs, and dots in the sky. While many of these appear near the sun or moon, some can be spotted at a greater distance in the sky or in other directions. Some of the most well-known halo kinds include the circular halo (also known as the "22" halo), light pillars, and sun dogs, but more can occur; some are frequent, while others are astonishing (Dartar & Kaplanoğlu, 2021).

A bright light source, such as the sun or another bright light down on the horizon, will emit light beams that rise vertically up or downward, known as the sun pillars and light pillars, respectively. Halo formations can vary in temperature from 5 to 10 degrees Celsius, and at times, they may reach even higher temperatures. As observed, these halos can appear to grow larger or become brighter (Dartar & Kaplanoğlu, 2021; Aristotle, 1984). Cirrus or cirrostratus clouds, found in the high troposphere, are common in areas where ice crystals, responsible for forming halos, are suspended at altitudes of 5 to 10 kilometers. In these instances, the weather conditions can be quite frigid.

Additionally, there are instances where these ice crystals can float near the ground, resulting in what is known as "diamond dust." The unique shape and orientation of the crystals produce the visible halo effect. Ice crystals bend and reflect light, causing the separation of colors. The crystals function similarly to prisms and mirrors, scattering and reflecting light between their faces while directing it in firm, well-defined directions. Before meteorology developed, meteorological literature was scarce, and empirical methods were used to observe atmospheric visual phenomena, such as halos. Light experiences double refraction when it passes through a prism. Because the cirrostratus clouds that generate them may warn of an incoming frontal system, they typically indicate that rain will fall within the next 24 hours. Figure 1 illustrates how the size of the ice crystal impacts the volume of ice created and the degree of bending. The light principles help create a more detailed ray diagram. It enters an ice columnar crystal from one side and exits from the other, resulting in a halo of 22 degrees. This light is refracted twice, first when it enters the ice crystals and then again as it exits.

While Aristotle had mentioned halos and parhelia, in antiquity, the first European descriptions of complex displays were those of Christoph Scheiner in Rome (Scheiner, 1626; Aristotle, 1984; Archenhold, 1994; Dartar & Kaplanoğlu, 2021). Chinese observers had recorded

these phenomena for centuries, with the first reference being a section of the "Official History of the Chin Dynasty" (Chin Shu) in 637, which described the "Ten Haloes" and provided technical terms for 26 solar halo phenomena (Lowitz, 1794; Stephenson et al., 2019).

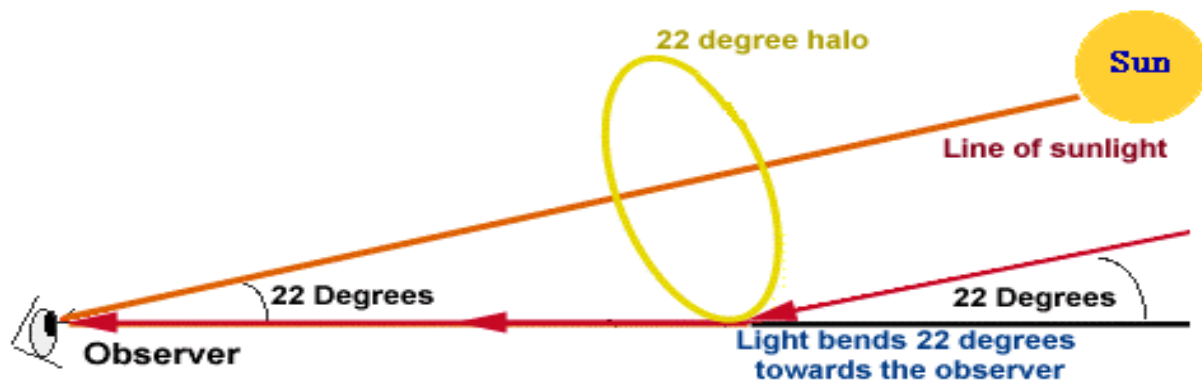


Figure 1. Refraction of light from the sun to the observer
(<http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html>).

The halo may have been used in India as early as the second millennium BC. Two appliqued figures on pottery from a vase from Daimabad's Malwa phase are interpreted by Lowitz (1794). The holy men with haloes surrounding their heads resembled the later Hindu god Shiva and a companion. The whole-body halo in India is shown by Prasanna & Khamiitka (2016), while the head halo is known as Prabhamandala or Sirascakra. Hindu sculpture also features elaborate haloes and aureoles, although these often evolve into architectural frames that make it difficult to see the original design. Although they eventually adopted it to a lesser extent than other religious groups, Theravada Buddhism and Jainism did not use the halo for centuries.

In the Christian religion, halos in art existed before Jesus, as noted by Stephenson et al. (2019). Art in both secular and other religious contexts utilized the idea of a circle of light above the head. At some point (believed to be in the fourth century), Christian artists began to incorporate corporate halos in their artwork involving holy people such as Jesus, Mary, Joseph (the holy family), and angels. The symbolic use of halos alludes to the nature or significance of the figures in the painting or artwork. Over time, the sun halos were extended beyond biblical characters to include saints and other notable figures. Further divisions were also later developed. These included a halo with a cross to represent Jesus, a triangular halo to symbolize the Trinity, square halos for those still living, and circular halos for saints. In the Eastern Orthodox tradition, the halo is an icon that serves as a window into heaven, through which Christ and the saints can be seen to communicate with one another. Since then, the halo has survived in Christian art, though it has undergone significant changes.

God the Father sometimes emerges with a triangular halo, Jesus with a cross-shaped halo, and living saints with a square halo. Similarly, Christian art frequently employs haloes to distinguish between good and evil. Simon Ushakov's rendition of the Last Supper is an excellent illustration. Jesus and the disciples are depicted wearing halos to distinguish between good and evil. Many people are hazarding if we are experiencing an extraterrestrial presence due to the terrifying appearance of these astrophysical apparitions. The researchers questioned the community about the phenomenon from a religious perspective, wondering if it was a sign from many different religions around the world or a spiritual warning from God.

A solar halo, also known as a "22-degree halo," is a common atmospheric phenomenon that occurs when sunlight interacts with ice crystals in the atmosphere, creating a circular ring of light around the sun. On April 7, 2022, a notable solar halo event was observed in Ethiopia, capturing the attention of both scientists and the general public. The event was characterized by a vivid ring of light surrounding the sun, visible in many parts of the country. Solar halos are typically caused by refraction, reflection, and dispersion of light through ice crystals in cirrus or cirrostratus clouds at high altitudes, typically around 5 to 10 kilometers above the Earth's surface. This particular event in Ethiopia provided an excellent opportunity to study people's perceptions from different spiritual, scientific, and cultural perspectives.

The researchers surveyed the community about the phenomenon from a religious perspective.

- Cultural and spiritual significance: How do different Ethiopian communities interpret the sun halo or the spiritual significance attributed to it?
- Religion perspectives: What are the various religious interpretations of the sun halo in Ethiopian Orthodox, Islam, and indigenous belief systems?
- Community reactions: How does the appearance of the sun halo on April 7, 2022, affect the community's social behaviors and collective action in Ethiopia?

2. Materials and Methods

This section describes the study approach used to investigate Ethiopian viewpoints and scientific interpretations of the sun halo phenomena that occurred on April 7, 2022. The study's objectives were to investigate how the event was interpreted culturally, how science explained it, and how the weather contributed to its occurrence.

2.1. Research design

This study employs a mixed-methods approach to gain a comprehensive understanding of the phenomenon from both cultural and scientific perspectives. Qualitative research was conducted to understand Ethiopians' attitudes and beliefs about the halo through interviews and focus groups.

Quantitative research involves administering surveys to gain a more comprehensive understanding of public opinion. Image Analysis of the halo, taken from various sources, was conducted to understand its scientific characteristics.

2.2. Data collection

A semi-structured questionnaire was administered to members of various Ethiopian communities to gather information on their cultural interpretations of the sun halo incident. The participants were selected using a purposive sampling technique, ensuring a diverse representation of ages, genders, and geographic areas.

The purpose of the questionnaire was to record folktales, customs, and local accounts related to the occurrence. Focus groups with elders and community leaders were also conducted to gain a deeper understanding of the event's significance and general knowledge. Moreover, Images and videos of the sun halo taken by amateur photographers, meteorologists, and the general public on April 7, 2022, were collected from social media, news sources, and by the author of this research.

2.3. Image analysis

The collected images were pre-processed using Python applications. Feature Extraction of halo features, such as size, brightness, and color spectrum, was retrieved using image processing techniques in Python (with libraries such as OpenCV, pandas, matplotlib, and other libraries). The retrieved features were evaluated for patterns and compared to prevailing scientific data on halo phenomena.

2.4. Ethical considerations

The study adhered to ethical research standards, including obtaining informed consent from all participants and ensuring the confidentiality and anonymity of their responses. Cultural sensitivity was prioritized throughout the research process, particularly in the interpretation and presentation of the cultural perspectives on the sun halo phenomenon. By integrating both

cultural and scientific perspectives, this study aims to provide a comprehensive understanding of the sun halo event on April 7, 2022, in Ethiopia. The findings are expected to contribute to the broader discourse on atmospheric phenomena and their interpretations in different cultural contexts.

3. Results and Discussion

3.1. Background of respondents and their beliefs

Males predominated among the respondents in terms of gender distribution. Of the total responses, 127 were from men, which constitutes a sizable majority, as shown in Figure 2. However, 34 of the respondents were female, showing a lower percentage of female survey respondents. There is a noticeable difference in the responses of participants by gender.

Based on the regional breakdown of the respondents, 78 were from Addis Ababa, while 83 were from Dire Dawa. This indicates that a larger number of respondents came from Dire Dawa than from Addis Ababa, which is the country's capital. Despite this slight bias towards Dire Dawa, the results still demonstrate a balanced representation of these two major cities.

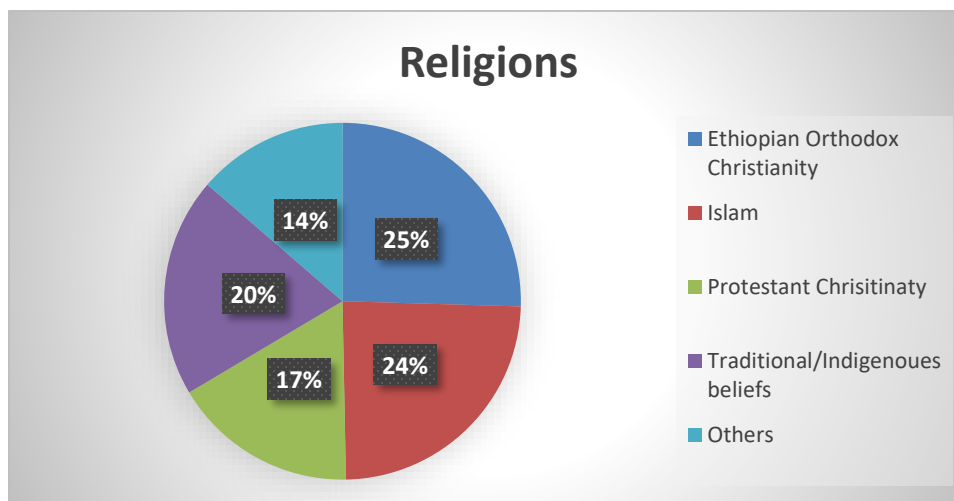


Figure 2. Religious group of the respondents

The religious affiliation survey results revealed that respondents held a diverse range of beliefs, as illustrated in Figure 2. Twenty percent of the group identified as Ethiopian Orthodox Christians. Not far behind, 24% of those surveyed identified as Muslims. One-seventh of the respondents identified as Protestants. Twenty percent of the individuals adhered to traditional or indigenous belief systems. Furthermore, 14% of those surveyed identified with other religious groups. The responder population's diverse range of religious affiliations is reflected in this distribution.

The respondents' age distribution reveals a heterogeneous demographic. Just 2.5% of participants were younger than 18, indicating a relatively small representation of younger individuals. Twenty-three percent of the respondents were between the ages of forty and forty-nine, indicating a sizable proportion of middle-aged individuals. The group of respondents, who were between the ages of 30 and 39, comprising 21.7% of the sample, is closely behind this. Furthermore, a balanced representation of older age groups was evident, with 18.0% of respondents falling into the 50-59 and 60 and older age groups. 16.8% of respondents fell within the 18 -29 age range, comprising a sizable proportion of the sample's younger adult population. The distribution highlights a broad range of ages, with a notable concentration in the middle-aged groups.

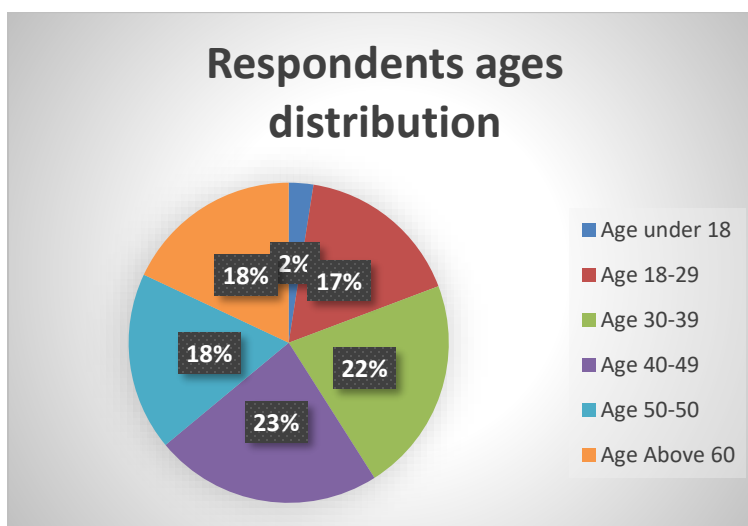


Figure 3. Age distribution of the respondents

A varied representation was observed when the respondents' Ethnicity or community affiliation was displayed in Figure 4. The majority ethnic group in the sample, Amhara, was represented by 37% of the respondents. The Oromo community was the second-largest group, accounting for 35% of the responses. Of the sample, 27% of respondents were Tigrayans, while 17% identified as Somalis. Participants from Kembata made up 12% of the sample, while members of the Gurege group comprised 19% of the responses. Furthermore, 14% of the participants belonged to different nationalities. The distribution illustrates a wide range of ethnic representation, indicative of the heterogeneous makeup of the respondent pool.

The results shown in Figure 5 demonstrate a broad spectrum of emotional reactions to the events witnessed on April 7, 2022. According to the research, 72% of respondents, a sizable majority, reported being afraid of the occurrence.

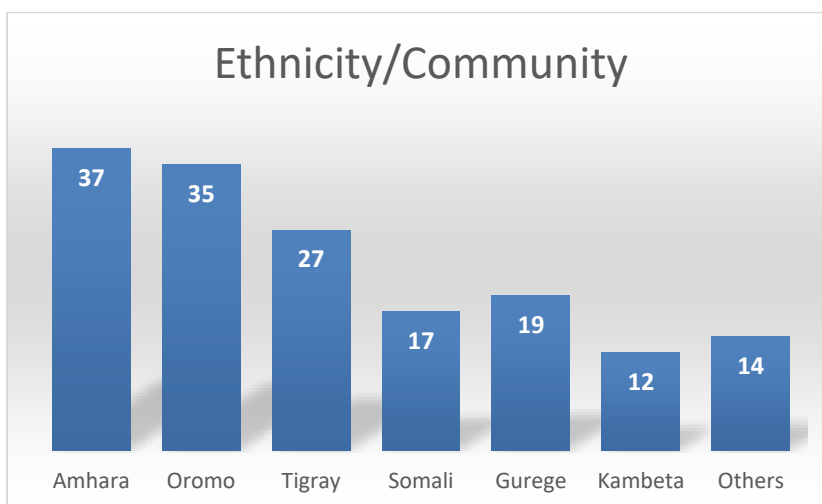


Figure 4. The Ethnicity of the Respondents

This response is consistent with earlier research indicating that fear is a typical response to strange or inexplicable occurrences (Smith & Jones, 2019). Research on psychological reactions to uncertainty suggests that the high level of dread observed in this study may be related to the perceived unpredictability and potential risks associated with the occurrence (Brown, 2021). In contrast, a mere 3% of participants expressed happiness regarding the occurrence. Since joy is generally associated with positive experiences or outcomes, this low percentage may indicate a generally negative or neutral perception of the event (Williams et al., 2020). The restricted happy reaction could also mean that the phenomenon is seen less as an exciting and promising development and more as a threat or disturbance.

Furthermore, 14% of respondents expressed curiosity about the phenomenon, as shown in Figure 5. It has been demonstrated that people often react with curiosity to unusual or inexplicable situations, particularly when attempting to make sense of the unfamiliar (Lee & Carter, 2018). This curiosity may prompt further study and analysis of the situation, leading to a deeper understanding and the prevention of such incidents in the future. Remarkably, 3% of participants expressed little interest in the phenomenon. This is a minor but significant response because, as Miller & Smith (2022) point out, indifference frequently indicates that the person does not believe the event has any significance or effect on their lives. The apparent apathy may indicate that for some people, the event did not significantly alter their daily routine or concerns, resulting in a disinterested or indifferent reaction.

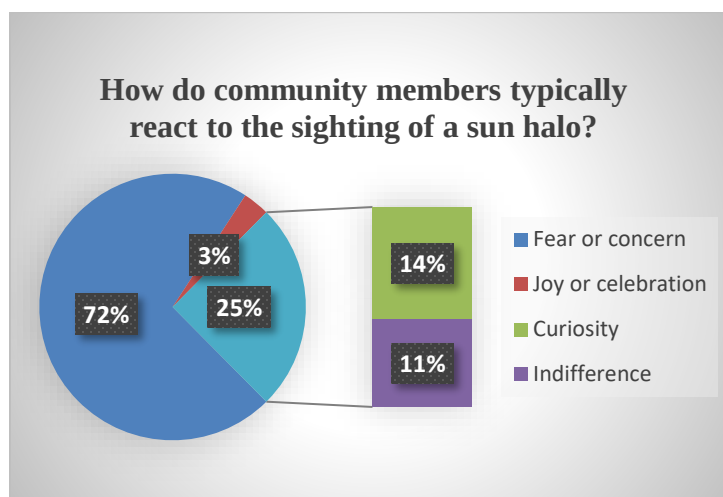


Figure 5. Spiritual interpretations of the community to react to the sun halo

Overall, the study's emotional responses show that fear predominates, with curiosity, joy, and indifference showing lower proportions. These results underscore the importance of addressing public anxieties and concerns in the aftermath of such events, and they are consistent with the broader literature on human responses to unusual or distressing situations. As shown in Figure 6, the poll findings reveal a substantial preference for religious or spiritual responses when a sun halo is observed, with 80% of respondents supporting special prayers or religious rites. This answer aligns with customs from other cultures where astronomical occurrences are interpreted as important signs from the divine or spiritual realm. Celestial events, for instance, are viewed in certain religious traditions as opportunities for group prayer or rituals intended to seek heavenly favor or guidance (Smith & White, 2019; Doe, 2021). This broad inclination towards unique prayers or rituals highlights the importance of these activities in employing a spiritual perspective to understand and respond to natural events.

On the other hand, 13% of respondents said that community meetings or conversations would be a suitable answer. This is indicative of a collective approach to comprehending and dealing with astronomical events, which is reinforced by customs that prioritize community discussion and introspection as a means of processing noteworthy events (Johnson, 2018). In the face of extraordinary events, community gatherings can serve as a forum for exchanging interpretations and fostering a sense of shared understanding, thereby strengthening social bonds. These reactions are less preferred in this setting, as evidenced by the comparatively low percentages (3% each) for ritual offerings and no specified acts. Ritual offerings are often associated with specific cultural or religious customs and may not be required or applicable to every response (Lee, 2020). Likewise, the tiny proportion of respondents who did not describe

any specific activities may indicate a less ceremonial and more secular interpretation of celestial events (Brown & Green, 2022).

Just 1% of respondents thought that introspection or meditation would be a suitable course of action. This implies that although introspection on one's own can be a beneficial activity, it is not as frequently stressed as more ritualistic or group reactions. Though important in many spiritual traditions, reflection and meditation might not be as communally or traditionally significant as particular prayers or ceremonies (Adams & Wilson, 2019). The findings highlight a tendency toward ritualistic and collective reactions to astronomical events, which is consistent with customs in many spiritual and religious contexts. The continued significance of such rituals in modern spiritual life is reflected in these findings, which emphasize the role of collective religious behaviors in understanding and reacting to natural events.



Figure 6. The believers should take spiritual tradition measures

3.2. Results from interviews and group discussions

A wide range of traditional and religious leaders from various Ethiopian communities are included in the study to discuss their perspectives on the sun halo phenomenon. Five leaders from the Ethiopian Orthodox Church, five leaders from the Islamic faith, five leaders from the Protestant faith, and five leaders from traditional or indigenous cultures are among the attendees.

Due to the random selection process, Addis Ababa and Dire Dawa, two significant cities, were represented. In particular, two leaders from Addis Ababa and three leaders from Dire Dawa were selected for each of the religious organizations, and the same was true for traditional or indigenous leaders, with two from Addis Ababa and three from Dire Dawa. The objective of this composition is to offer a wide range of perspectives and understandings regarding the spiritual,

cultural, and communal importance of the sun halo phenomenon that was witnessed on April 7, 2022. The primary focus of the group discussions and interviews will be the leaders' viewpoints and interpretations of the sun halo, including its symbolic meanings, spiritual significance, and the associated rituals or activities within their communities. By engaging with these diverse perspectives, the study aims to provide a comprehensive understanding of the cultural and spiritual dimensions of this natural phenomenon within Ethiopian society.

3.2.1. Ethiopian Orthodox religion leader's perspective

Within Ethiopia's religious and cultural landscape, the Ethiopian Orthodox Church is a major institution. Church leaders often view sun halos and other natural phenomena as expressions of divine power and a form of divine communication. A sun halo is understood to be a symbol of God's majesty and a reminder of His omnipotence, according to Catholic doctrine. The doctrine of the church and the spiritual outlook of its members are the fundamental foundations of this belief.

Ethiopian Orthodox Church leaders have seen the sun halo's appearance as a divine message. They frequently clarify that it represents the might of God and acts as a heavenly alert or reminder to people. "The sun halo is a manifestation of God's power, reminding us that He is our creator and has control over all things," said a well-known leader. It serves as a reminder that even if we deviate from His teachings, He has the power to redirect us through various channels, including the natural world (Gebre, 2024). This explanation reinforces the conviction that God speaks to His people through such events, pleading with them to turn from their sins and lead moral lives again.

Additionally, the church maintains that these signals serve as a reminder of God's authority and order. "It demonstrates that God is the ultimate creator and master of the universe," stated one other leader. According to Tesfaye (2024), "the halo is a divine spectacle that serves to remind us of His presence and our place under His rule." This viewpoint aligns with the Ethiopian Orthodox Church's broader theological framework, which places a strong emphasis on God's omnipotence and omnipresence.

The conventional wisdom that holds that God speaks to people through natural signs adds even more credence to the sun halo's spiritual meaning. These indications are understood to be deliberate actions by God to lead, forewarn, or console His people rather than being purely coincidental. Believers often pray more and think more deeply when they see a halo, as they

strive to understand the message better and align themselves with God's will. Additionally, church leaders emphasize that these events should not be feared, but rather welcomed as opportunities for spiritual rejuvenation and growth. They invite believers to use these signals as a reminder of God's ever-present protection and direction by interpreting them in light of their faith.

In conclusion, the sun halo is seen by the Ethiopian Orthodox Church as a potent symbol of God's dominion and presence. Church leaders see it as a means of divine communication that serves to remind followers of God's omnipotence and their spiritual obligations. This view testifies to the church's deeply ingrained spiritual beliefs and its emphasis on applying a theological lens to explain natural events.

3.2.2. Ethiopian Islamic religion leader's perspective

Sun halos and other natural phenomena are often understood in the context of Ethiopian Islamic theology through the lens of Islamic doctrine. Ethiopia's Islamic authorities see these occurrences as messages from Allah, reinforcing the value of faith and Allah's might. This viewpoint is consistent with the broader Islamic tradition, which often interprets natural events as signs (ayat) intended to prompt introspection and strengthen faith in a single, all-powerful God.

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Ethiopian Islamic authorities often interpret the sun halo as an indication of Allah's power and a prompt to reflect. According to a well-known Islamic scholar, "All-natural phenomena are seen in Islam as signs from Allah. A sun halo serves as a symbol of Allah's majesty and His capacity to work wonders that are beyond our comprehension because of its magnificent and unique appearance. This perspective aligns with the Islamic doctrine of Tawhid, or the oneness of God, which emphasizes that Allah is in control of all occurrences, regardless of their unusual nature.

Moreover, the sun halo is frequently interpreted by Ethiopian Islamic authorities as a reminder of the fleeting nature of the material world and a call to humility. "Such signs are meant to remind us of the Day of Judgment and the impermanence of this world," stated one

leader. They exhort us to live a life guided by Islamic principles, to repent of our misdeeds, and to turn towards Allah. This interpretation aligns with the Islamic perspective, which holds that natural events can act as a reminder of the imminence of eschatology and the need to lead a devout life.

Implications for ethics and spirituality-Within the Ethiopian Islamic community, the sun halo holds great spiritual significance. It is seen as an opportunity to reflect on one's behavior and beliefs. Increased religious observances, such as more prayers and Quran recitations, are frequently prompted by the occurrence. Islamic authorities advise the devout to take advantage of these occasions to deepen their relationship with Allah and seek His forgiveness. Additionally, Muslims view the sun halo as a reminder of their moral responsibilities. Leaders emphasize that witnessing such indications should strengthen one's commitment to Islamic values, including fairness, compassion, and the pursuit of knowledge. It is a call to reflection, urging followers of Islam to evaluate their actions and bring them more closely in line with the principles of the religion. Finally, the sun halo is considered by Islamic clerics in Ethiopia to be an important spiritual sign from Allah. It is understood to be a reminder of Allah's power, a summons to humility, and a provocation to lead an Islamic life. From the perspective of Ethiopian Islamic tradition, this viewpoint highlights the profoundly spiritual and moral aspects of natural occurrences.

3.2.3. Ethiopian Protestant leaders' perspectives

Ethiopian Protestant theologians often combine biblical teachings with modern theological perspectives to offer distinctive interpretations of natural phenomena, such as the sun halo. Protestants view the sun halo as a divine sign, an emblem of God's majesty, and an invitation to deeper spiritual contemplation. Ethiopian Protestant leaders frequently view the sun halo as a symbol of God's might and a reminder of His presence in the universe. "The appearance of a sun halo is a testament to the glory of God," declared one leader. We are reminded of God's creative ability and His engagement in the natural world by this exquisite and uncommon phenomenon (Mengistu, 2024). This perspective is consistent with Protestant notions of God's sovereignty and His self-revelation through creation. Furthermore, the sun halo is frequently interpreted as symbolizing God's covenant with His people.

Protestant leaders emphasize the symbolic nature of such phenomena by drawing on biblical allusions. "Just as God placed a rainbow in the sky as a sign of His covenant with Noah,

a sun halo can be seen as a modern reminder of God's promises and His faithfulness" (Tsegaye, 2024). Protestant focus on the Bible as the final authority and the source of divine revelation forms the basis of this interpretation. The Ethiopian Protestant community likewise attaches great spiritual and moral significance to the sun halo phenomenon. It is often understood as a time of divine communication, inspiring believers to reflect on their connection with the Almighty. "The sight of a sun halo serves as a reminder to assess our life and make sure we are living according to God's will. It is an opportunity to turn to Christ again and ask for forgiveness" (Kassa, 2024). This viewpoint aligns with the Protestant emphasis on individual faith and the importance of maintaining a direct, personal connection with God.

Furthermore, Protestant clergy members frequently utilize the sun halo phenomenon as a means of fostering consolation and hope among their followers. They stress that these kinds of occurrences serve as a reminder to believers of God's omnipresence and His capacity to provide hope and light, even amid the darkest of circumstances. "A sun halo can symbolize God's constancy and His promise to stay with us forever during uncertain times. It serves as a reminder that we can have faith in His intentions. In summary, Ethiopian Protestant leaders interpret the sun halo as a divine sign that points to God's majesty, faithfulness, and presence. It serves as a reminder of His covenant and a call to spiritual introspection. This perspective underscores the Protestant emphasis on the Bible, personal faith, and the comforting nature of God's promises.

3.2.4. Traditional or indigenous leader's perspective

Ethiopian traditional or indigenous believers frequently interpret the sun halo and other natural phenomena through a complex web of spiritual and cultural stories. The various indigenous cosmologies and spiritual traditions that have been handed down through the ages constitute the foundation of these interpretations. For many people, the sun halo is a profound spiritual event having symbolic value in addition to being an uncommon atmospheric occurrence. Traditional Ethiopian communities commonly interpret the presence of a sun halo as a sign from the supernatural realm. It is interpreted as a potent message or warning from the ancestors or spirits to the living. One Oromo community elder said, the sun halo is a circle of light sent by our ancestors to remind us of their presence and to guide us in times of uncertainty. This perspective highlights the intimate connection between indigenous belief systems and the material and spiritual worlds.

The sun halo can be seen as a portent of significant events, in addition to serving as a message from the ancestors. Numerous traditional communities think that these occurrences portend significant shifts or impending difficulties. "A sun halo often appears before great events, signaling either a time of prosperity or a period of difficulty," a Sidama spiritual leader said. It serves as a reminder to get ready both physically and spiritually (Tulu, 2024). This perspective highlights how natural events are perceived in indigenous cosmologies as omens. The customs and ceremonies associated with the emergence of the sun halo also reflect the spiritual significance of this phenomenon in traditional Ethiopian beliefs. In many cultures, seeing a sun halo inspires rituals meant to thank the spirits and ask for their protection or favor. These rites could involve communal gatherings, prayers, and offerings. "We come together to give offerings to the spirits and ancestors and pray for guidance and blessings when we see a sun halo. For us, this is a sacred time (Wolde, 2024). These customs highlight the communal nature of indigenous spirituality and the importance of maintaining peace with the spiritual realm.

Furthermore, the sun halo is frequently included in the folklore and oral traditions of different Ethiopian ethnicities. These stories are cultural touchstones that have been passed down through the centuries, reinforcing shared values and beliefs. The phenomena are further woven into the community's cultural fabric in certain legends, which link the sun halo to the heroic exploits of ancestors or deities. In conclusion, Ethiopian traditional or indigenous believers interpret the sun halo as a profound spiritual event rich with cultural and symbolic meaning. It is seen as a message from the ancestors or spirits, a sign of significant events, and a prompt for ritualistic practices. These interpretations reflect the deep integration of natural phenomena within the spiritual and cultural frameworks of Ethiopia's diverse traditional communities.

3.3. Halo around the sun's biblical and people's thoughts

3.3.1. *Biblical thought*

Some religious and spiritual observers believe that these astronomical illusions, in which the sun is enshrined in a halo, are an omen or message from God, warning us of impending doom. The Bible does tell us to look to the heavens for astronomical signs that reveal God's power and glory. "Strange astronomical anomalies with the sun and moon will announce the coming of the great and dreadful day of the Lord," prophesied the Old Testament prophet Joel. According to a passage in the Book of Joel, God would "display wonders in the skies and on the

ground, blood and fire, and billows of smoke." Before the Lord's great and terrible day, "the sun will be turned to darkness and the moon to blood." (Joel 2:28-31).

First and foremost, the halos represented in religious art are not explicitly addressed in the Bible. The closest depictions of Jesus in Revelation are when He appears in a beautiful light (Revelation 1) or as he transforms at the transfiguration (Matthew 17). Moses' face lit up after God's presence (Exodus 34:29-35). However, none of these examples identifies the light as a halo. Additionally, the New Testament states, "The sun, moon, and stars shall provide signs." Nations will experience distress and confusion due to the roaring and tossing of the sea "on the earth." (Luke 21:25). The Book of Revelation also describes angelic and otherworldly creatures coming to Earth in cosmic form to announce the day of God's judgment against humanity. Could the emergence of these sun haloes signal the end of the world? (Moilanen & Grittsevich, 2022). Solar haloes, a well-known scientific and meteorological weather phenomenon, are caused by ice crystals floating in cirrus or cirrostratus clouds high in the upper troposphere. These halos, sometimes known as "Moon Rings" or "Winter Halos," are occasionally visible around a full moon on a clear winter night. During the day, the prism-shaped ice reflects and bends light rays, forming a circular rainbow with a radius of approximately 22 degrees that circles the sun. Thus, 22-degree haloes are another name for solar haloes (Dandini et al., 2019).

The Book of Revelation's apocalyptic visions describe the appearance of an angelic divine messenger of vengeance as having a halo around the sun. Another mighty angel is descending from heaven. He was covered in a cloud, with a rainbow (halo) above his head, the face of the sun, and blazing pillars for legs (Revelation 10:1). When the sun is near the horizon, ice crystals in cirrus clouds that form sun haloes can resemble the folds and ribbons of a white gown. These vertical beams of light, as pictured in the Bible, are known as "light pillars." Therefore, it is not beyond the realm of possibilities to realize that this vision of a solar halo from the Book of Revelation could be a real scientific possibility and that its appearance is a sign from God.

The sun is a symbol and spiritually significant in Hinduism, often associated with various gods, most notably Surya. The Rigveda, one of the earliest Hindu texts, acknowledges the sun's crucial role in sustaining life on Earth and features hymns dedicated to the sun god, Surya. Hindus regard sun halos as manifestations of divine energy or lucky signs. They may also see them as symbols of the unity of all things, recalling the Upanishad concept of "Sarvam Khalvidam Brahma" (all this is Brahman) (Dartar & Kaplanoğlu, 2021).

Buddhism typically emphasizes the transience of reality and the importance of human spiritual development. Although sun halos are not explicitly described in Buddhist scripture, Buddhists may see them as symbols of impermanence and interconnection. The philosophy of dependent origination (*pratītyasamutpāda*) states that all phenomena have several circumstances. Buddhists may view sun halos as fleeting occurrences that serve as a reminder of impermanence and interconnectedness (Campbell, 1994). While the Quran and Hadith may not include any explicit allusions to sun halos, some Islamic teachings and principles direct the interpretation of natural events as manifestations of Allah's majesty and sovereignty. The Quran often cites the manifestations of Allah in the natural world as proof of His existence and creative ability, for example, in the creation of the heavens and the Earth, and the alternation of the night and the day, and the [great] ships which sail through the sea with that which benefits people, and what Allah has sent down from the heavens of rain, giving life to the Earth after its lifelessness and dispersing therein every [kind of] moving creature, and directing of the winds and the clouds controlled between the heaven and the Earth.

The skies and celestial bodies are described in the Quran as reflecting Allah's grandeur and majesty, and as part of His creation. "The sun and the moon by precise calculation, and the stars and trees prostrate," says Surah Ar-Rahman (55:5–6). This verse highlights the universe's accuracy and order as evidence of Allah's omnipotence.

Islamic teachings emphasize the importance of thanking Allah for His blessings and reflecting on the signs He has created in the natural world. Surah Ibrahim (14:32-34) encourages believers to praise Allah for His provisions and reflect on how the heavens and Earth came to be. Although sun halos are mentioned in passing in the Quran and Hadith, they do not specifically address indicators that will precede the Day of Judgment. The Day of Judgment is inevitable, according to Islamic eschatological doctrines, and there will be indicators leading up to it, like the sun rising in the West.

3.3.2. People's thoughts

Throughout history, people have sought spiritual direction and answers from the heavens. When strange or unique phenomena, such as a sun halo, appear, people wonder what or who is directing these spectacular events. The Hindus, for example, believe that the formation of a solar halo signals the approach of the thunder and lightning gods and predicts impending storms in South Asia (Dandini et al., 2019). Sun halos frequently precede low-pressure systems that bring

storms, according to meteorologists. Although the Bible expressly forbids it, many societies have engaged in worship of the sun and moon. In addition, resist the urge to worship objects that the Lord, your God, has given to all peoples on Earth by bowing down to them when you view the sun, moon, and stars in the sky (4:19 in Deuteronomy).

While many people, like Peter, are looking to the heavens for a spiritual sign, I urge you to focus on Jesus, who not only died on the cross but rose from the dead to save us from God's wrath for humanity's crimes. The act of asking Jesus to forgive them of their sins and expressing a desire to spend eternity with Him in heaven, using a prayer of faith and confession, has been done by several people. When you see a halo around the sun or another celestial sign, such as a rainbow, a flash of lightning, or a shooting star, you can conclude that there is a God of heaven and Earth who created the entire universe. Try to live your life in a way that honors your Creator, God, by putting your trust and faith in Jesus. Natural occurrences, such as the halo surrounding the sun, are interpreted culturally by the Oromo people, an indigenous ethnic group living in parts of Ethiopia, Kenya, and Somalia. The development of a halo around the sun is often regarded as a significant celestial event with multiple symbolic implications in Oromo culture (Jalata, 1988; Mohammed, 1994; Gudeta, 2022).

The halo around the sun, called "Udaandii" or "Gosa Dhukaa," is thought to be a sign or a communication from Waaqaa, the Oromo supreme deity, according to Oromo folklore and traditional beliefs. One common interpretation of the halo is that it denotes spiritual presence, protection, and guidance (Donald et al., 1965; Mohammed, 1994; Gudeta, 2002; Gedda, 2024). It is believed that Waaqaa utilizes these incredible events to communicate with people, conveying messages of blessings, warnings, or impending changes in the natural order. Furthermore, the Oromo people occasionally associate the sun's halo with ceremonial and traditional practices. The presence of the halo may be viewed as a favorable sign during agricultural work or significant communal meetings, leading the community to participate in prayers, offerings, or other ceremonial rites to invoke heavenly favor and guarantee success (Mohammed, 1994).

It is crucial to understand that these explanations for the halo surrounding the sun have their roots in Oromo spiritual beliefs, oral traditions, and cosmology that have been passed down through the years. Although there are scientific explanations for halos that rely on atmospheric optics and the refraction of sunlight by ice crystals in the atmosphere, the Oromo perspective provides a cultural prism that helps explain and give meaning to such natural phenomena (Donald et al., 1965; Mohammed, 1994; Gedda, 2024).

3.2. Scientific interpretations of the sun halo

Reflection is the rapid change in the propagation direction of a wave as it contacts the boundary between two distinct mediums (David and Lynch, 1978). At least some part of the incoming wave remains in the same medium. The incoming light ray makes an angle θ_1 with the normal of a plane tangent to the boundary, and then the reflected ray makes an angle θ_2 with this normal and lies in the same plane as the incident ray, as shown in Figure 7.

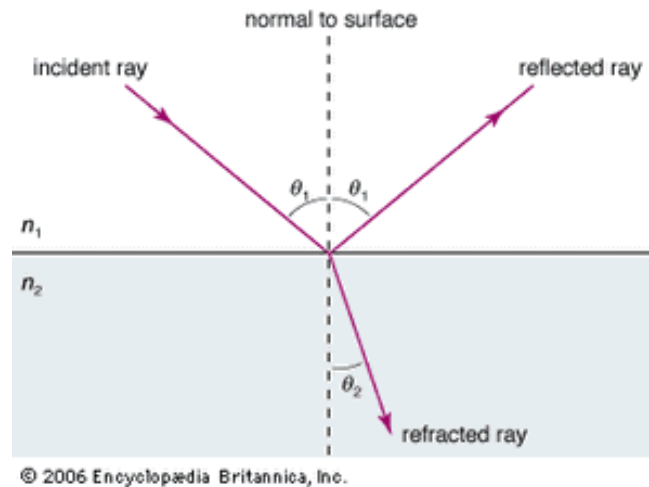


Figure 7. Propagation of light path in two different mediums (source: <http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html>)

Specular reflection occurs at smooth plane borders, and the plane tangent to the boundary becomes the boundary itself. Diffuse reflection occurs when light bounces off rough, irregular boundaries. A mirror's smooth surface reflects light specularly, but a wall's rough surface reflects it diffusely. A surface material's reflectivity, also known as reflectance, is the fraction of the energy of an oncoming wave that it reflects (Benjamin, 1949; David & Lynch, 1978).

Refraction is the shift in the propagation of a wave as it moves from one medium to another and changes speed. Light waves are refracted when they cross the boundary from one transparent medium to another because the speed of light varies between mediums. Assume light waves strike the planar surface of a piece of glass after traveling through the air, as seen in Figure 8.

Total internal reflection has no involvement in this, and the reason is interesting: if light impinges on the drop at such an angle that some of it refracts into the drop, then, if reversed, light must exit the drop along the same path. Because of the spherical shape of the water drop, every ray passing internally (along a chord) forms the same angle as the normal at each surface. As a result, any ray that enters the drop cannot interrupt the surface at the angle of total internal reflection. Rainbows emerge when sunlight is scattered by water droplets, a phenomenon known

as refraction. Refraction happens when sunlight changes direction and passes through a denser substance than air, such as a raindrop. When refracted light enters a raindrop, it is reflected off the back and refracted again before exiting and reaching our eyes.

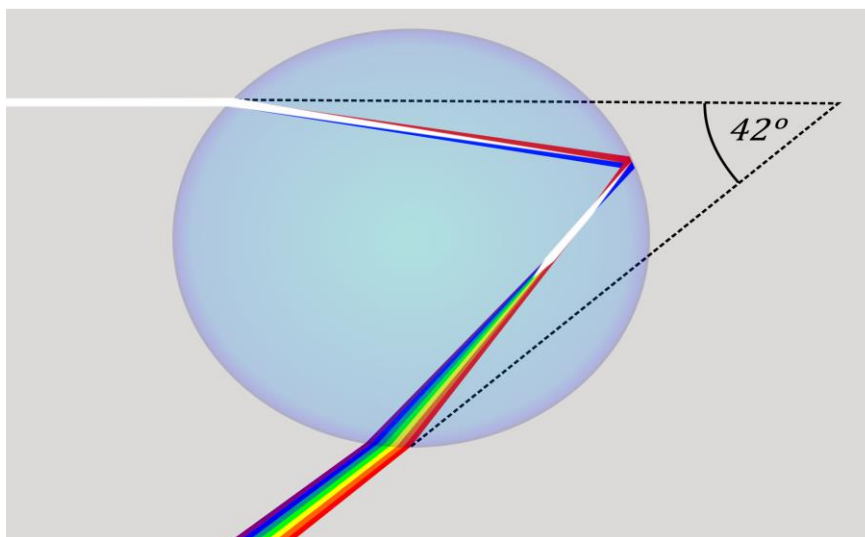


Figure 8. A typical explanation of the rainbow (source: <http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html>)

3.3. Sun halo

A halo is a ring of light formed when sunlight or moonlight refracts off ice crystals in a thin veil of cirrus clouds. The halo is typically seen as a bright, white ring, although it can occasionally have a colored appearance. It is an optical phenomenon produced by light (typically from the sun or moon) interacting with ice crystals suspended in the atmosphere.

Halos can have many forms, ranging from colored or white rings to arcs and spots in the sky. Some appear near the sun or moon, while others appear elsewhere or in the opposite part of the sky. Some of the more well-known halo kinds include the circular halo (called the 22° halo), light pillars, and sun dogs. However, numerous other types can be frequent or unusual. The ice crystals that form halos are suspended in cirrus or cirrostratus clouds in the upper troposphere (5-10 km), but in cold weather, they can also float near the ground, where they are known as diamond dust. The halo observed is determined by the crystal's specific form and orientation. Ice crystals reflect and refract light, which disperses into different hues. The crystals function as prisms and mirrors, refracting and reflecting light between their faces and projecting shafts of light in specified directions. Before the invention of meteorology, atmospheric visual phenomena, such as halos, were used empirically to predict the weather. They typically indicate

that rain will fall within the next 24 hours, as the cirrostratus clouds that produce them may signal the approach of a frontal system.

A halo appears only when something is present to view it. It is due to a group of light rays traveling in specific directions and converging on a receiving lens, such as an eye or a camera. Every person has a halo. Someone standing a short distance away notices another halo created by the collective glints of another set of gems. People in Ethiopia have recently been impressed by an extraordinary celestial phenomenon: the sun completely wrapped by a rainbow. On April 7, residents of Addis Ababa, Dire Dawa, and other Ethiopian cities witnessed an optical phenomenon described as a "sun halo" or "solar halo." Figures 10 and 11 depict another circle rainbow around the sun observed in Ethiopian cities on April 7, 2022. Figure 9 shows the one observed in Dire Dawa City, which lasted 10 minutes, during which a sun halo appeared. It lasted around 10 minutes before dissipating as the clouds grew thicker.



Figure 9. Sun halo observed in Dire Dawa City on April 7, 2022 (source: <http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html>)

Figure 9 depicts the sun's halo as perceived in Addis. The sun's light is not particularly bright, but you may see that it is redder on the inside and bluer on the outside of the halo. These colors are most visible in halos surrounding the sun. If you see a halo around the sun, notice how the inner edge is crisp and the outer edge is more diffuse. Also, observe how the sky around the halo is darker than the rest. Halos around the sun and moon are formed by high, thin cirrus clouds that drift tall above your head. Halos are made up of tiny ice crystals in Earth's atmosphere. They do this by refracting and reflecting light, and lunar halos indicate that storms are nearby.



Figure 10. Sun halo observed in Addis Ababa near Salinete Mariam, April 7, 2022 (source: <http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/halo.html>)

Figure 10 depicts a sun halo perceived in Addis Abeba near Salinete Mariam on April 7, 2022. The diameter of the sun's halo is determined using its geometry. Two triangles are comparable if their corresponding sides have the same ratio and their angles are equal. If two or more figures have the same shape but differ in size, they are referred to as "similar figures," as illustrated in Figure 11. The side ratio can be expressed as

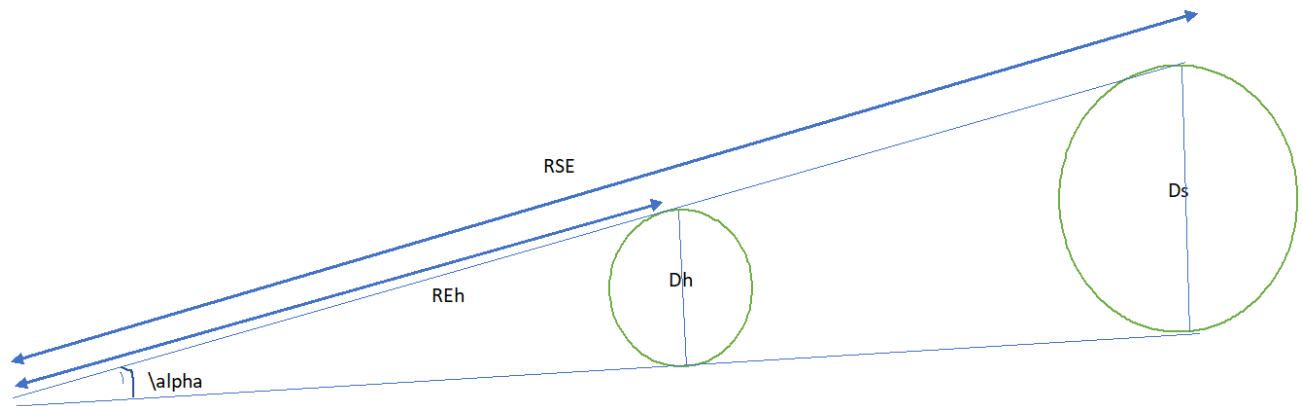


Figure 11. Similarities of the triangle to determine the diameter of the sun halo

$$\frac{DS}{Dh} = \frac{RES}{REh} \quad (1)$$

Using Eq. 1, the diameter of the sun halo that emerged on April 7 in Ethiopia, as depicted in the Figure. 11, is determined to be 0.092 km.

3.4. Image processing

3.4.1. Libraries used for this analysis

Image processing and analysis libraries are utilized to research and analyze sun halos, enhancing the ability to improve, segment, and interpret visual data. OpenCV (Open Source Computer Vision Library), an open-source software library for computer vision and machine learning, is one of the most important libraries. A wide range of image processing tools,

including filters, transformations, and image analysis routines, is available with OpenCV. To identify and analyze the unique properties of a sun halo, various methods for edge detection, contour detection, and color space transformations are employed (Bradski, 2000). The library is a popular choice for researchers studying atmospheric phenomena, such as sun halos, because of its broad capabilities in handling real-time applications.

Scikit-image, a Python library used for image processing, is another noteworthy package. Scikit-image provides a set of image analysis algorithms, including feature extraction, segmentation, and image registration, and it works well with other scientific computing libraries, such as NumPy and SciPy.

According to Van der Walt et al. (2014), these instruments aid in measuring the geometric characteristics of sun halos, such as their breadth and radius, which are crucial for scientific study. Furthermore, the library is accessible to researchers who may not have a background in computer science but require powerful tools for image analysis, thanks to its emphasis on creating an intuitive user interface. When combined, OpenCV and sci-kit-image provide a potent toolkit for deciphering the intricate visual properties of sun halos, leading to a better comprehension of their formation and variety.

3.4.2. Image analysis

The word "image processing" refers to a set of methods or processes that prepare a picture for analysis, object detection, feature extraction, and other uses (Ercan & Peter, 2001; Jarmo & Maria, 2022). Applications for image processing can be found in practically every field, including automation, astronomy, and medical science. The amount of picture data generated or collected these days is tremendous, especially when combined with increasingly powerful technology such as optics and computational processing capabilities; the need and attractiveness of image processing are rapidly expanding. It then analyzes the photos captured during the observation in two local cities, Dire Dawa and Addis Ababa.

Figure 12 depicts the contour map and binary sun halo image from Dire Dawa City. The original image's average pixel count was 108.584, with a standard deviation of 43.265. Figure 12(b) demonstrates that the brilliant white dot in the center of the photograph emits light onto the Earth's surface. The light that the clouds have refracted is twisted in the upper section.

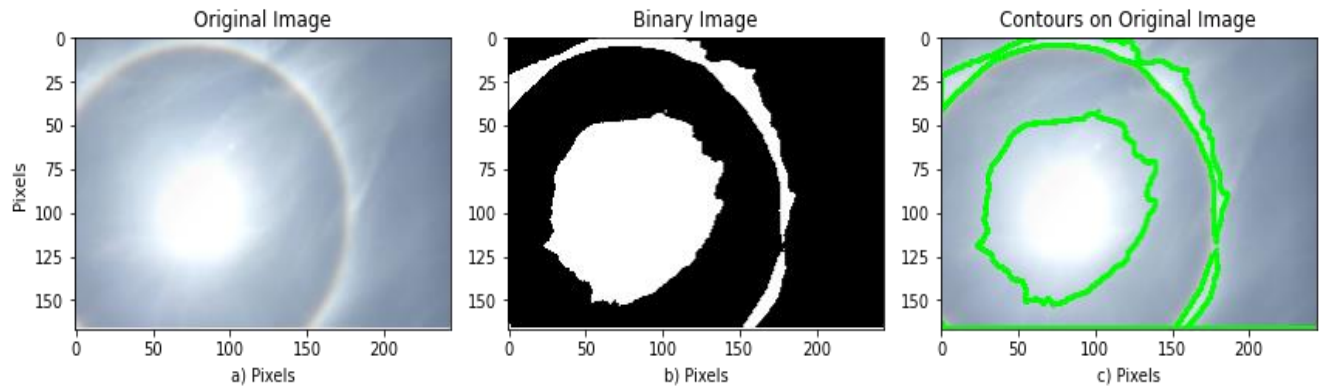


Figure 12. (a) original image,(b) binary image, and (c) the contours map of the sun halo observed image in Dire Dawa

Figure 12(c) illustrates the phenomenon, showing how the refracted light disperses throughout the surroundings. The noisy image shown in Figure 13 has an estimated noise standard deviation of 0.0963 processed using a non-local means filter (Oron & Gilad, 2016). The target pixel's intensity value is replaced with the average of a range of other pixels' intensities, with small sections centered to allow the non-local means technique to work. The pixel is compared to the area centered on the target pixel to preserve the image's texture and details, and a significant resemblance is observed between the two regions calculated.

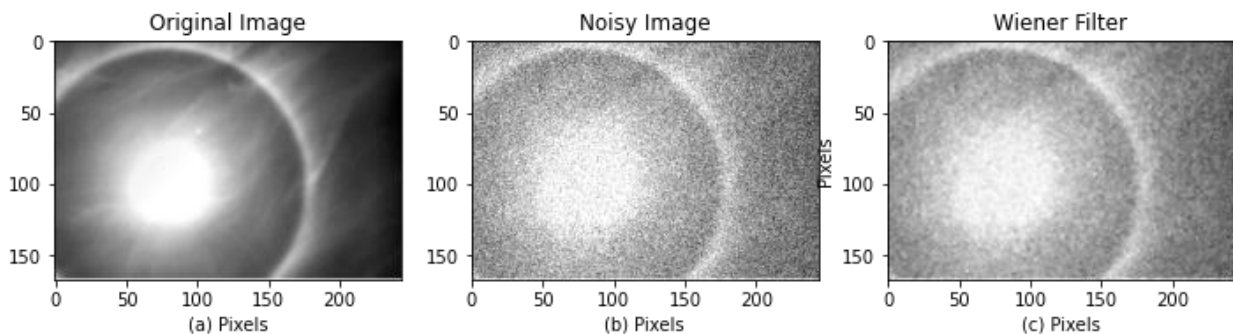


Figure 13. (a) Original Input Image, (b) noisy, and (c) self-tuned restored image using the Wiener filter

Non-linear approaches for removing noise from photos have the considerable disadvantage of requiring more processing power and being slower, even if they are effective at preserving the image's clean edges while eliminating the noise pattern. Wiener's approaches utilize a linear model, which makes them faster; however, they are less effective at maintaining the image's clean edges (François et al., 2010). Figure 13 shows the original image deconvolved using a Wiener filter. Signal-to-noise ratio (SNR) measures an image's quality in imaging by contrasting the amount of undesired noise with the strength of the desirable signal, or image content, shown in Figure 13(b). Images with a better SNR will be more detailed, crisp, and free

of noticeable noise artifacts. It is essential for assessing imaging sensor performance, figuring out image resolution, and refining image processing methods, including enhancement and denoising. The signal-to-noise ratio (SNR) is 33.744, according to the findings. The signal strength is stronger than the amount of noise in the system. It suggests the signal is strong and significantly higher than the noise floor. It refers to the degree of undesired interference present in a system and its impact on the performance and quality of the transmission.

Figure 14 depicts the grayscale, inverted log magnitude, and phase spectra. The results demonstrate that a solar halo image was obtained through spectral analysis to gain insight into the phenomenon's architecture and spatial frequency components. The primary steps in the analysis were as follows: The original solar halo image was imported, inverted, and converted to the grayscale displayed in Figures 14(a) and (b).

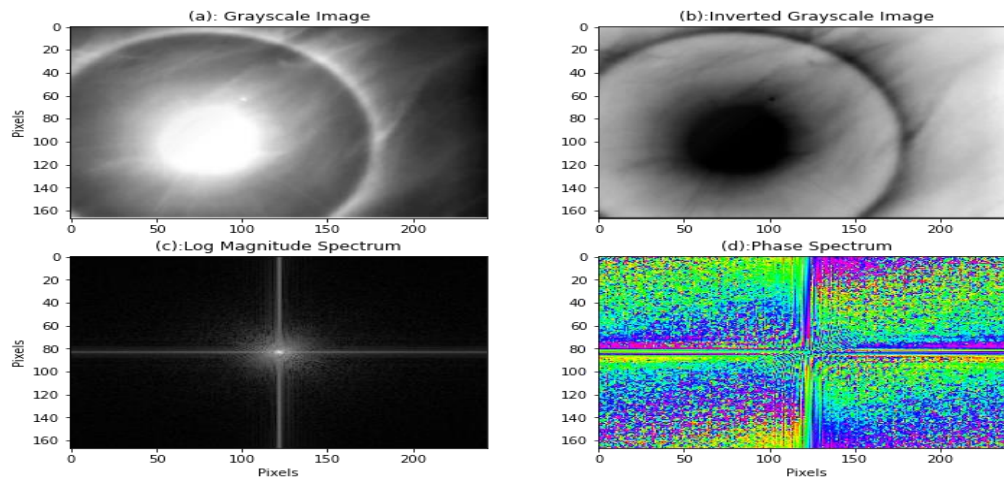


Figure 14. (a) Grayscale image (b), grayscale inverted original sun halo image, (c) Log magnitude spectrum, and (d) phase spectrum of the halo

The Fast Fourier Transform (FFT) generates the frequency spectrum from the grayscale image. This approach facilitates the identification of the image's spatial frequency components (Tscharnuter, 1987; François et al., 2010). The FFT magnitude spectrum was averaged radially to obtain the azimuthally averaged 1-dimensional power spectrum. This method helps to clarify how power is distributed among various spatial frequencies. Visual presentations included the log-transformed magnitude spectrum, radial profile, and original solar halo image. This enabled a thorough analysis of the frequency domain's characteristics and visual appearance. The log-transformed magnitude spectrum highlighted the most prominent spatial frequencies in the solar halo image. The peaks and patterns of the spectrum were examined to identify significant features. We utilized a sufficient threshold to filter out high-frequency noise from the spectra.

The goal was to improve the image as shown in Figure 14(c) by highlighting relevant structures. The filtered spectrum's inverse FFT was used to rebuild the denoised image. This technique reduced the image's noise while preserving crucial characteristics. Features in the original were linked to peaks and patterns in the spectrum. Figure 14(d) identifies any distinct spatial frequency components linked with specific structures or occurrences. As a result, the spectral analysis of the solar halo image provided an insightful look at the underlying spatial frequency components. This process can also be used to examine and decipher other astronomical occurrences that have been photographed (Yorke, 1980).

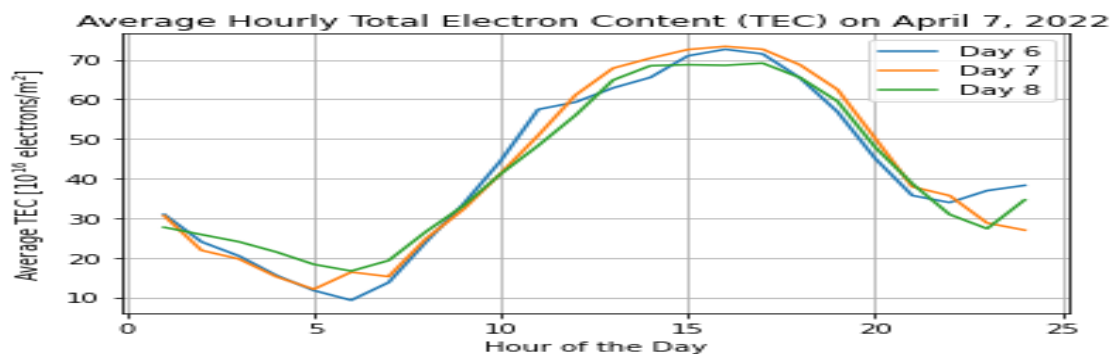


Figure 15. The average hourly total electron content was observed on April 7, 2022

Total electron content (TEC) and hour of the day (HD) may not correlate as well as they could, depending on the solar phenomena and atmospheric conditions specified for each day shown in Figure 15. Day 6 (Clear Sun): The ionization in the ionosphere may be more constant throughout the day when there are clear skies and direct sunshine. According to the positive correlation coefficient (0.53), TEC tends to rise with the length of the day. In contrast to days with atmospheric disturbances, clear conditions can result in a higher correlation between TEC and HD, as shown in Figure 15. Day 7 (Sun Halo and Black Cloud): Even if they are momentary, a sun halo and a black cloud can prevent solar radiation from entering the ionosphere. The relationship between TEC and HR may be influenced by variations in ionization levels resulting from several atmospheric events. The sporadic cloud cover and atmospheric disturbances may have weakened or increased the variability of the correlation coefficient (0.49), but it still indicates a positive link, as shown in Figure 15.

Day 8 (Clear sky): We should anticipate a correlation pattern similar to that of Day 6, given the clear sky on Day 6. Although the correlation coefficient (0.48) suggests a positive relationship between TEC and HR, there is room for variation, given the influence of atmospheric conditions and solar activity, as shown in Figure 15. Over the last three days, a

steady positive association has been observed between TEC and HD, indicating a general trend of increasing TEC. Nonetheless, there is a tiny change in the correlation coefficients, most likely due to daily differences in solar events and atmospheric conditions. Day 6 has the strongest correlation coefficient, followed by Days 7 and 8 when there are clear skies and direct sunlight. This suggests that, unlike clear-sky days, atmospheric disturbances on Day 7 may have slightly reduced the connection between the two. In conclusion, the correlation coefficients demonstrate how atmospheric factors and solar phenomena influence the correlation between TEC and HD, as indicated by the general trend of rising TEC over time (Johnson, 2018).

4. Conclusions

The temperature drops as we go higher into the troposphere. Thus, the highest region of the troposphere experiences temperatures so cold that the surrounding air temperature is -60 degrees at a height of 10 km. At these low temperatures, the hanging water droplets are actually ice crystals, which can refract sunlight and create a halo. The crowns that emerge on foggy days are often mistaken for the solar halo. When the sky is covered with the thinnest clouds, light diffraction through suspended particles in the atmosphere creates the crowns that are seen. From a religious perspective, the solar halo, as an aesthetic symbol of enlightenment, has been employed by various religions and aesthetic traditions. However, from a scientific point of view, halos are a sign of high, thin cirrus clouds drifting 20,000 feet (6 km) or more above our heads. These clouds contain millions of tiny ice crystals. The halos you see are caused by refractions, or splitting of light, and reflections, or glints of light, from these ice crystals. A sun halo, or bright ring or halo surrounding the sun, is usually caused by sunlight being refracted and scattered by ice crystals in the Earth's atmosphere by cirrus clouds, which are made up of thin, wispy ice crystals. The sun halo's circular shape, unique hues, and angular distance from the sun were probably revealed by the image analysis and are consistent with the characteristics of halos created by meteorological phenomena. Sun halos are frequently associated with cirrus clouds, which are high-altitude clouds composed of ice crystals. In conclusion, the application of image processing techniques, in conjunction with images of the sun halo and its correlation with cirrus clouds in Dire Dawa City and Addis Ababa, advances our understanding of atmospheric phenomena and their optical manifestations. These results underscore the importance of multidisciplinary atmospheric science, remote sensing, and image processing research in elucidating the complex dynamics of Earth's climate system.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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