ORIGINAL ARTICLE

A newly released forage oat (*Avena sativa*) variety "WAS" registered for the central highland areas of Ethiopia

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ABSTRACT

Fifteen oat accessions including the standard check (SRCP X 80Ab 2291) were tested for forage dry matter yield, herbage qualities, pest and disease reaction and other agro-morphological characteristics across three locations (Holetta, Jeldu, and Kulumsa) during the main cropping seasons of 2016-2018. Based on the overall performance, three superior accessions (CI-1589, CI-1506, CI-633) were selected and verified with the standard check at Holetta, Adaberga, and Kulumsa agricultural research centers and sub-site in 2018 cropping season. The candidate accession CI-1506 which produced better forage DM yield across locations and years was released. Combined analysis indicated that forage DM yield ranged from 15.5 to 18.6 t/ha with a mean of 16.6 t/ha. The released accession CI-1506 gave the highest DM yield followed by CI-1589 while CI-633 and the recently released standard check varieties produced comparable yields. The candidate accessions (CI-1589, CI-1506) had forage dry matter yield, crude protein yield, and digestible yield advantages over the standard check. The released accession has percent increase advantages of 18.5, 44.4, and 18.74% in DM yield, CP yield, and IVDMD yield over the recently released standard check variety, respectively. Among the accessions, the released variety named Was (CI-1506) had the highest forage dry matter yield, crude protein yield, and digestible yield advantages over the standard check and other candidate varieties. Moreover, the candidate accessions (CI-1589, CI-1506) had leaf to stem ratio, crude protein content, and in-vitro dry matter digestibility content advantages over the standard check. Similarly, the released variety Was (CI-1506) had a relatively better leaf to stem ratio (12.5%), CP (2.6%), and IVDMD (0.2%) advantages over the standard check variety (SRCP X 80Ab 2291). The national variety releasing committee evaluated the accessions at field conditions in October 2018. Based on their evaluation result, Oat variety Was (CI-1506) was officially released in November 2019 for production in the high altitude areas and similar agro-ecologies of the country. The pre-basic and basic seeds of the released variety Was (CI-1506) variety are maintained by feeds and nutrition research programs of Holetta Agricultural Research Center.

Keywords*:* Oats, quality, variety release, variety verification, yield

INTRODUCTION

Oat (*Avena sativa* L.) is an annual crop used for human food and livestock feed worldwide (Peterson *et al*., 2005; Achleitner *et al*., 2008). Oat is grown in more than 50 countries but statistical information is mainly concerned with the food grain (Heuzé *et al*., 2016). Oat remains an important grain crop for people in marginal ecologies throughout the developing world, and also in developed countries (Suttie and Reynolds, 2004). Livestock grain feed is still the primary use of oat crop, accounting for an average of around 74% of the world's total usage in 1991 to 1992 (Welch, 1995). As compared to the other crops, oat is broadly adapted to marginal environments with low fertility soils (Boonman, 1995; Hoffman, 1995; Buerstmayr *et al*., 2007; Ren *et al*., 2007) and tolerates acidic soils with pH ranging from 4.5 to 8.6 (Heuz et al., 2016). Similarly, Stevens *et al*. (2004) found that oat is well adapted to a wide range of soil types but perform better on acid soils. Oat mostly grows in cool moist climates at temperatures ranging from 5 to 26°C and rainfall over 500 mm (Ecoport, 2013). But the crop can be sensitive to hot and dry weather mostly from head emergence to maturity (Suttie and Reynolds, 2004). Among other cultivated forage crops, oat is widely utilized in the highland farming system of Ethiopia. It is best adapted to cool, moist climates and it grows satisfactorily from 1750 to 3000 meters (Fekede, 2004; Getnet *et al*., 2004) but at lower altitudes, it is less suitable as tillering is limited and no dense canopy is formed (Fekede, 2004). Lulseged (1991) and IAR (1987) have also reported that experiments done in the different testing sites in the highlands showed adaptations to waterlogging, resistant to diseases except for rust, performs better on poor soils.

Testing oat accessions at Holetta and probably in Ethiopia was started towards the end of the 1960s. Accessions of oat were introduced from European countries including Holland, Sweden, Russia, and various states of the USA. Nineteen accessions were initially introduced from USA in1969 (IAR, 1970), and then in 1973 many accessions of world collections were introduced and about 650 accessions advanced and maintained for further evaluation (IAR, 1975). Based on farmers' request grain and dual (forage and grain) oat accessions were also introduced from CIMMYT in the 1980s. These accessions are maintained at Holetta and utilized until now as a germplasm source for various research purposes. So far, a total of 10 oat varieties have been officially registered in the crop variety register book (MoANR, 2019). The introduced varieties of oat are mixed up and conceived as one variety by farmers, they do not utilize different oat varieties for various purposes or farming practices, such as different varieties for different soil types, early or late-maturing varieties, seed sizes and forage types, etc. It is a dual purpose crop and is used as both forage and grain worldwide (Fekede, 2004; Suttie and Reynolds, 2004). It produces an abundance of excellent fodder at the time when other succulent better quality fodders are scarce and it can be fed green and the surplus converted into hay and silage for use during the scarcity period. Moreover, oats grain makes a good balanced concentrate in the ration for poultry, cattle, sheep and other animals. Different studies also indicated that oat grain is used as livestock feed (Fekede, 2004; Getnet et al., 2004; Gezahagn et al., 2016; Nikoloudakis, 2016). In Ethiopia, it can be grown in pure stands, in mixtures and cultivated on residual moisture or as a precursor to other crops (Getnet, 1999; Fekede, 2004; Muluneh *et al*., 2014.

`The farming systems of the highlands have a lot of agricultural production constraints. Population pressures led farmers to cultivate grazing and other marginal lands. Feed shortage becomes very critical in most of the areas this orients farmers to maximize productivity per unit area, labor, and input. This indicates that it is high time to look at technologies that best fit the farming system. Research on forage productivity and other relevant aspects of oat was started more than four decades in the highlands of Ethiopia. As there were no any formal releasing mechanisms like that of other food crops, oat was demonstrated and seeds were distributed informally to farmers around Arsi, and the central highlands in the outer reaches of Addis Ababa (Sheno, Sululta, Debre Berhan, Selale, and Holetta) and some other areas for forage production. Over time farmers popularize oat for various purposes mainly for food grain in addition to forage production. To improve the availability of livestock feed in terms of quantity and quality, it is better to cultivate oat that has better biomass yield and nutritional quality. The variety release mechanism for forage and pasture crops has been established and officially implemented since 2009 in the country (Fekede *et al*., 2015). So the promising oat varieties for different production systems should be officially registered and released for various end-users. Therefore, this paper presents the forage yield performance, nutritional qualities, agro-ecological adaptation, disease reaction, and other morpho-agronomic and management recommendations for the recently released oat variety named Was (CI-1506).

MATERIALS AND METHODS

Description of the Test Environments

The experiment was executed at the Jeldu sub-site and Holetta and Kulumsa Agricultural Research Center in the central highlands during the main cropping seasons of 2016-2018 under rainfed conditions. The rainfall of the study sites is bimodal and about 70% of the precipitation falls in the period from June to September, while the remaining 30% falls in the period from March to May. The trial sites' geographical position and physicochemical properties of the soil are summarized in Table 1.

Table 1. Description of the test locations for the physiographic location and physicochemical soil properties.

Parameters	Holetta	Jeldu	Kulumsa
Latitude	9° 3' 19''N	9°16′28''N	08°05′22''N
Longitude	38° 30' 25''E	38°05′32''E	39°10′30''E
Altitude (masl)	2400	2800	2200
Distance from Addis Ababa (km)	29	113	167
Annual Rainfall (mm)	1044	1200	820
Daily minimum temperature (°C)	6.2	2.06	10.5
Daily maximum temperature (°C)	21.2	16.9	22.8
Soil type	Nitosol	Nitosol	Luvisol
Textural class	Clay	Clay	Clay loam
pH(1:1 H_2O)	5.24	-	6.0
Total organic matter (%)	1.80	-	5.50
Total nitrogen (%)	0.17	-	0.25
Available phosphorus (ppm)	4.55	-	-

Experimental Design and Layout

One hundred fifty oat accessions were evaluated at Holetta research center for one cropping season and best performing twenty accessions were selected and advanced for further evaluation at Holetta and Jeldu locations for two cropping seasons. Based on agronomic performance data, fifteen best performing accessions were selected and promoted to an advanced variety of trials for two years at Holetta, Jeldu, and Kulumsa trial sites. Similarly, based on two years of agronomic and nutritional quality performance data, three best-performing oat accessions (CI-1589, CI-1506, and CI-633) were selected for a variety verification trial with the standard check variety (SRCP x 80Ab 2291) at Holetta, Jeldu and Kulumsa research sites in 2018 cropping season. Non replicated 10m x 10m plot size was used for verification of the accessions. The recommended seeding rate of 100 kg/ha was used at sowing and the seed was sown in rows of 20 cm. Diammonium Phosphate (DAP) fertilizer at the rate of 100 kg/ha was uniformly applied for all accessions during sowing. All recommended management practices were applied for all accessions during the experimental periods.

Data Collection and Measurements

Measurements on plant height were taken randomly from three plants in each plot using height measuring meter from the ground level to the tip of the panicle. For the determination of biomass yield, varieties were harvested at the soft dough stage. Weight of the total fresh biomass yield from sample area (1.8 m^2) was recorded from each plot in the field and the estimated 500 g of their representative samples were taken from each plot to the laboratory. The estimated 500 g sample taken from each plot was weighed to know the sample fresh weight using sensitive table balance and manually fractionated into leaf and stem. The morphological parts were separately weighed to know their sample fresh weight, oven-dried for 72 hours at a temperature of 65^{o}c, and separately weighed to estimate the proportions of these morphological parts. The proportion of each morphological fraction in percent was then computed as the ratio of each dry biomass fraction to total dry biomass multiplied by 100. The crude protein yield was calculated by multiplying crude protein content with total biomass yield and then divided by 100%. The digestible yield was also determined by multiplying IVDMD with total biomass yield and then divided by 100%.

Laboratory Analysis

The oven-dried samples, at a temperature of 65^{o}C for 72 hours, were used for laboratory analysis to determine the chemical composition and *in-vitro* dry matter digestibility of the accession. The dried samples were then ground to pass a 1-mm sieve and the ground samples were used for laboratory analysis. The analysis was made for the different nutritional parameters. Total ash content was determined by oven drying the samples at 105^{0}C overnight and by combusting the samples in a muffle furnace at 550^{o}C for 6 hours (AOAC, 1990). Nitrogen (N) content was determined following the micro-Kjeldahl digestion, distillation, and titration procedures (AOAC, 1995), and the crude protein (CP) content was estimated by multiplying the N content by 6.25. The structural plant constituents like neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest and Robertson procedure (1985). The *in-vitro* dry matter digestibility (IVDMD) was determined according to the Tilley and Terry procedure (1963).

Statistical Analysis

Differences among varieties were tested using analysis of variance procedures of the SAS general linear model to compare treatment means (SAS, 2002). The model was mathematically represented as: $\mathbf{Y_{ijk} = \mu + G_i + E_j + (GE)_{ij} + B_{k(j)} + e_{ijk}}$; Where, $\mathbf{Y_{ijk}}$ = measured response of genotype i in block k of environment j; $\boldsymbol{\mu}$ = grand mean; $\mathbf{T_i}$ = effect of genotype I; E_j = effect of environment j; **GE**= genotype and environment interaction; $\mathbf{B_{k\,(j)}}$ = effect

of block k in environment j; e_{ijk} = random error effect of genotype i in block k of environment j. The least significant difference (LSD) was used for comparison of means at a 5% significance level.

RESULTS AND DISCUSSION

Adaptation

The released oat variety named Was (CI-1506) is well adapted for the high altitude areas of the country (MoANR, 2019). The variety performed very well in areas with an altitude of 1500 to 3000 meters above sea level which has an annual rainfall of 700 to 1500 mm. It could also be possible to extend the production of the released variety to other areas with similar agro-ecologies after doing adaptation trials. The released variety produces better forage DM yield when recommended fertilizer rate and seeding rate are applied on nitosol and other soil types at planting. Generally, the released variety has better forage DM and seed yields performance in the high altitude areas when the variety sown after the first shower of rain in June.

Varietal Evaluation

Three best-performing oat accessions (CI-1589, CI-1506, and CI-633) were selected from fifteen accessions to conduct Variety Verification Trial (VVT). The selected three accessions of oat were sown at Holetta and Kulumsa Agricultural Research Centers and Jeldu sub-site of Holetta during the main cropping season of 2018. The National Variety Releasing Committee (NVRC) evaluated the performance of accessions at field conditions in October 2018 and based on their evaluation result, oat variety Was (CI-1506) was officially released in November 2019. The mean plant height performance of the accessions over locations is indicated in Table 2. The result indicated that the released variety Was (CI-1506) had relatively higher mean plant height when compared to the recently released standard check variety.

Table 2. Average plant height (cm) of oat varieties as compared to the standard check tested at Holetta, Jeldu, and Kulumsa in 2016-2017 cropping seasons

	Location			
Variety	**Holetta**	**Jeldu**	**Kulumsa**	**Mean**
1589	174.2^{a}	140.0^{b}	155.6^{a}	156.6^{a}
1506	168.9^{a}	120.9^{c}	136.5^{b}	142.1^{b}
633	152.8^{b}	155.0^{a}	156.7^{a}	154.8^{a}
SRCP X 80Ab 2291 (SC)	137.2^{b}	113.3^{c}	138.4^{b}	129.6^{c}
Mean	**158.3**	**132.3**	**146.8**	**145.8**
CV (%)	8.15	9.3	8.8	12.5
LSD	15.7	14.9	15.7	12.1

SC= Standard check; Means followed by different superscript letters within a column are significantly different from each other at P<0.05

Agro-Morphological Characteristics

The released oat variety Was (CI-1506) adapted well and gave better forage dry matter yield in the highland areas ranging in altitude from 1500 to 3000 masl. The released variety is performed very well in the areas where an annual rainfall ranging from 700 to 1500 mm. The released variety has better performance when planted in red nitosol areas. The variety should be planted with a seeding rate of 75-100 kg/ha at 20 cm row spacing in early June. At planting, DAP fertilizer at a rate of 100 kg/ha should be applied for better establishment. The released variety should be harvested at the soft-dough stage to get optimum biomass yield and herbage qualities. The released variety Was (CI-1506) requires 100 to 110 days after planting to reach the forage harvesting stage (soft dough stage). At the forage harvesting stage, the variety has a better leaf to stem ratio which is a good indication of quality feed. The mean forage dry matter yield of 18.6 t/ha, crude protein yield (1.30 t/ha), digestible yield (10.01 t/ha), seed yield (26.1 qt/ha) and straw yield (13.5 t/ha) are recorded for the released variety Was (CI-1506). The thousand seed weight and harvest index of the released variety ranged from 20 - 25 g and 0.14 - 0.17, respectively. Generally, the released variety has better quality in terms of the leaf to stem ratio, CP, and IVDMD when compared to the recently released standard check variety. A summary of agro-morphological and nutritional characteristics of the released oat variety Was (CI-1506) is indicated in Table 3.

Yield Performance

The forage yield of tested oat varieties is indicated in Table 4. The highest mean DM yield was obtained at Kulumsa (21.2 t/ha) followed by Jeldu (15.3 t/ha) while the lowest (13.1 t/ha) was recorded for Holetta. The released variety Was (CI-1506) relatively produced better forage DM yield across locations and years. The combined analysis indicated that forage DM yield ranged from 15.5 to 18.6 t/ha with a mean of 16.6 t/ha. Generally, the released variety Was (CI-1506) gave the highest DM yield followed by CI-1589 while CI-633 and the recently released standard check varieties produced comparable yields. Forage DM yield differences occurred due to variations among the tested genotypes, testing environments, and genotype x environment interaction effects. The rank

of the varieties for forage DM yield could vary across the test environments indicating the occurrence of the varietal interaction for this trait across the test environments. When genotypes perform consistently across locations, breeders can effectively evaluate germplasm with a minimum cost in a few locations for the ultimate use of the resulting varieties across wider geographic areas. However, with high genotype by location interaction effects, genotypes selected for superior performance under one set of environmental conditions may perform poorly under different environmental conditions.

Table 3. Agronomical, morphological and nutritional characteristics of oat variety Was (CI-1506)

Characteristics	CI-1506
Species	*Avena sativa*
Common name:	Oat
Variety name:	Was (ዋስ) (CI-1506)
Adaptation:	For highland areas
Soil type:	Nitosol
Altitude (m.a.s.l):	1500 – 3000
Rainfall (mm):	700 – 1500
Seeding rate (kg/ha):	75 – 100
Row planting (kg/ha)	75
Broadcasting (kg/ha)	100
Spacing for row planting (cm):	Inter-rows 20
Planting date:	Early June
Fertilizer rate (kg/ha):	100 kg DAP or 46/18 kg N/P_2O_5
Time of fertilizer application:	DAP at planting
Plant height at forage harvest (cm):	130 – 160
Days to forage harvesting (soft dough stage):	100 – 110
Days to seed harvesting:	125 – 145
Leaf to stem ratio	1.5 – 1.8
Yield (qt/ha):	
Forage dry matter (DM):	160 – 230
Seed:	20 – 30
CP:	10 – 15
Digestible:	80 – 100
Straw:	120 – 150
1000 seed weight (gm):	20 – 25
Harvest index (%):	14 – 17
Fodder quality (g/kg DM):	
Ash:	119
CP:	78
NDF:	727
ADF:	485
ADL:	105
IVDMD:	538
Year of release	2019
Breeder/maintainer	HARC

The result indicated that the candidate varieties except for CI-633, had better forage DM yield, CP yield, and digestible yield advantages over the standard check (Table 5). The released variety had percent increase advantages of 18.5, 44.4, and 18.74% in DM yield, CP yield, and IVDMD yield over the recently released standard check variety, respectively. Generally, the released variety Was (CI-1506) had better DM yield, CP yield, and IVDMD yield advantages over the recently released standard check variety and other candidate varieties. The average seed yield of the varieties and their seed yield advantages over standard check variety are indicated in Table 6. Accordingly, the released variety Was (CI-1506) had low seed yield performance when compared to the standard check variety.

Table 4. Average forage DM yield (t/ha) of oat varieties as compared to the standard check tested over locations in 2016-2017 cropping seasons

	Location			
Variety	Holetta	Jeldu	Kulumsa	Mean
1589	14.1^{ab}	14.5	20.5	16.4
1506	16.7^{a}	16.0	23.1	18.6
633	9.7^{c}	17.6	19.3	15.5
SRCP X 80Ab 2291 (SC)	11.9^{bc}	13.3	21.8	15.7
Mean	13.1	15.3	21.2	16.6
CV (%)	23.0	21.5	33.9	32.5
LSD	3.7	4.0	8.8	3.6

SC = Standard Check; Means followed by different superscript letters within a column are significantly different from each other at P<0.05

Table 5. Average dry matter yield, crude protein, and *in-vitro* dry matter digestible yields advantage of oat varieties over the standard check

Variety	DM yield	% increase	CP yield	% increase	IVDMD yield	% increase
1589	16.4	4.5	1.11	23.3	8.87	5.22
1506	18.6	18.5	1.30	44.4	10.01	18.74
633	15.5	-1.3	0.75	-16.7	8.31	-1.42
SRCP X 80Ab 2291 (SC)	15.7	-	0.90	-	8.43	-

SC= Standard check

Table 6. Average seed yield (qt/ha) of oat varieties and their mean seed yield advantage over the standard check variety.

	Locations				%
Variety	Holetta	Jeldu	Kulumsa	Mean	increase
1589	21.1^{b}	22.2	23.0	22.1^{b}	-44.5
1506	29.1^{b}	22.5	26.7	26.1^{b}	-34.4
633	44.3^{a}	31.1	35.4	37.3^{a}	-6.3
SRCP X 80Ab 2291 (SC)	44.4^{a}	28.1	47.0	39.8^{a}	-
Mean	34.7	26.2	33.0	31.3	
CV (%)	26.3	32.4	22.6	33.9	
LSD	11.1	10.3	9.1	7.1	

SC= Standard check

Quality Attributes

The chemical composition and *in-vitro* dry matter digestibility of oat varieties are presented in Table 7. The ash content of candidate oat varieties showed a difference, ranging from 119 to 125 g/kg DM. The higher ash content in forage could be an indication of high mineral concentration. The concentration of minerals in forage varies due to factors like plant developmental stage, morphological fractions, climatic conditions, soil characteristics, and fertilization regime (Jukenvicius and Sabiene, 2007). The CP content of the candidate varieties ranged from 77 to 79 g/kg DM. Under high temperatures in the tropics, there is rapid growth and development of grasses resulting in a high rate of decline in the proportion of leaves concerning stems which reduce CP content and digestibility. The IVDMD content of the tested candidate varieties ranged from 536 to 541 g/kg DM. The decline in digestibility of matured oat may be attributed to the observed declines in CP content, and an increase in detergent fibers and the degree of lignification. The NDF content ranged from 725 to 734 g/kg DM. The decline in digestibility may, therefore, have been mainly due to the fiber chemistry and anatomical structure of the cell wall rather than its content. The candidate varieties had advantages over the standard check variety in terms of the leaf to stem ratio, CP, and IVDMD (Table 8). The result showed that the released variety Was (CI-1506) had leaf to stem (12.5%), CP (2.6%), and IVDMD (0.2%) advantages over the standard check variety.

Table 7. Chemical compositions and *in-vitro* dry matter digestibility of oat varieties

	g/kg DM					
Variety	Ash	CP	NDF	ADF	ADL	IVDMD
1589	121	79	725	478	91	541
1506	119	78	727	485	105	538
633	125	77	734	487	94	536
SRCP X 80Ab 2291 (SC)	107	76	748	509	112	537

SC= Standard check

Table 8. Leaf to stem ratio, crude protein and *in-vitro* dry matter digestibility advantages of oat varieties over the standard check

Variety	LSR	% increase	CP	% increase	IVDMD	% increase
1589	1.66	3.7	7.9	3.9	54.1	0.7
1506	1.80	12.5	7.8	2.6	53.8	0.2
633	1.80	12.5	7.7	1.3	53.6	-0.2
SRCP X 80Ab 2291 (SC)	1.60	-	7.6	-	53.7	-

SC= Standard check

Reaction to Diseases and Pests

Data recording on major diseases and pests was done for oat varieties over the years and locations. Based on the standard rating scale of 1-9, where 1 is highly resistant and 9 is highly susceptible, the varieties were found to be tolerant to moderately tolerant for the recorded major disease and pests in the test locations during the experimental periods. The released oat variety Was (CI-1506) was tested for its diseases and pests reactions starting from the initial stage of evaluation to verification stage and found to be tolerant to major diseases and pests which can affect the variety. The tolerance reaction of the variety could be integrated with other diseases and pests management strategies for better results. Generally, the released variety had superior tolerance to major diseases and pests as compared to the standard check.

Conclusion

Oat varieties respond differently for agronomic performance and nutritive values across the test environments due to differential responses of the varieties to various edaphic, climatic, and biotic factors. Measured agronomic traits such as plant height, leaf to stem ratio, forage DM yield showed variations among the tested varieties and environments. The released variety Was (CI-1506) adapted and gave better yield in the highland areas ranging in altitude from 1500 to 3000 masl. The performance of the released variety is promising in the areas where an annual rainfall ranging from 700 to 1500 mm. The released variety has better forage biomass yield and seed yield on nitosol and other soil types. The released variety produces better forage DM yield and seed yield when a recommended fertilizer rate and seeding rate are applied at planting. The nutritional qualities indicated that the candidate varieties had advantages over the standard check variety in terms of the leaf to stem ratio, CP, and IVDMD contents. Generally, the released variety Was (CI-1506) had relatively better leaf to stem ratio, CP and IVDMD contents advantages over the standard check variety. Therefore, the national variety releasing committee evaluated the varieties at field conditions in October 2018. Based on their evaluation result, oat variety Was (CI-1506) was officially released in November 2019 for production in the high altitude areas and similar agro-ecologies of the country. The pre-basic and basic seeds of the released variety are maintained by feeds and nutrition research programs of Holetta Agricultural Research Center.

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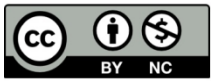

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