Outstanding Performance of Recently Released Linseed (Linum usitatissimum L.) Variety (Yadanno) and Other Linseed Lines in South Eastern Highlands of Ethiopia

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Abstract
Yadanno is a common name for the linseed variety developed through hybridization and continuous selections using pedigree method. *Yadanno* was selected, developed and released by Kulumsa Agricultural Research Center for Arsi and West Arsi Zones and similar agro-ecologies of linseed growing areas of Ethiopia. Specifically, it was tested at Kulumsa, Bekoji, Asasa and Kofele for three years (2010/11 to 2012/13) and verified in 2014/15 at listed locations for 2016 official release. As a result, *Yadanno* consistently produced better mean seed and oil yields than the standard check *(Kulumsa-1)* and the local check over three years. Likewise, it proved to be resistant to wilt (*Fusarium oxysporum f.sp. lini*), powdery mildew *(Oidium sp.)* and pasmo *(Septoria linicola)* diseases. The results of the multi-location trials revealed that *Yadanno* was superior in seed and oil yields performance across years and locations. Besides, it is stable variety based upon different stability parameters.
Keywords: Edible Oil; *Yadanno*; Linseed; Variety registration
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INTRODUCTION

Oil crops occupy third position following cereal and pulse crops in the agricultural economy of Ethiopia. Among oil crops linseed (*Linum usitatissimum* L.) is one of the ancient oilseeds cultivated for oil, food and fiber (Lay and Dybing, 1989; Nozkova, *et al*., 2016). Ethiopia is considered the secondary center of diversity and the 5thmajor producer of linseed in the world after Canada, China, United States and India (Adugna, 2007), later on she became the 7th major producer (FAOSTAT, 2017). Linseed is an annual and self-pollinated crop. Among oil crops linseed is the third important commodity next to sesame (*Sesamum indicum* L.**)** and noug (*Guizotia abyssinica* Cass.) in Ethiopia. But, it is the second and the first important oil crop in Oromia Regional State and Arsi Zone, respectively (CSA, 2017). During 2015/16 cropping season, 746,581 subsistence farmers allocated 85,415.67 hectares of land for linseed production and produced 88,551 tons of linseed with an average yield of 1.04 t/ha (CSA, 2016). It occupies 10% of the total area cultivated for oilseeds with 11.3% of the total annual oilseeds production in the country. Earlier time area of linseed was increased from 142,899 hectares (ha) in 2003/04 to 180,873 ha in 2008/09. In the same years, its production and average yield were also increased from 0.77 to 1.56 million quintals and from 541 to 863 kg ha-1, respectively. However, area and production of linseed dramatically decreased by 125% and 78% when we compare data of last eight years data (CSA, 2009; CSA 2017), nevertheless its productivity improved by 27%. The realized reductions could be attributed mainly to: inherent low productivity of the crop, market volatility, consistent tax exempted edible oil importation like palm oil, lack of international collaboration on the crop improvement and development efforts, lack of germplasms exchange, limited government budget support, limited extension support, less suitability of the crop for mechanized operations, consistent market price increase for cereal and pulse crops specially for wheat and faba bean, and better availability of mechanized and pesticides technologies and services for competent commodities like bread wheat.

Linseed was widely cultivated in higher elevations of Ethiopia where frost was a threat for other crops including other oilseeds (Getinet and Nigussie, 1997). It is an important pre-cursor crop for cereal, pulse and potato crops in South Eastern Highlands of Ethiopia (Abebe and Adane, 2015). Typically, linseed consists of approximately 40% fat, 28% dietary fiber, 21% protein, 4% ash, and 6% carbohydrates (Vaisey-Genser and Morris, 2010). Linseed has wide and incredible uses: it is a source of food, feed, fiber, oil, medicine, and industrial raw material and export commodity. Linseed cake is rich in microelements, vitamins, dietary cellulose, proteins (up to 38%) (Altai, 2010). Linseed has long history of cultivation by smallholder farmers, exclusively for its oil in the traditional agriculture of Ethiopia (Hiruy and Nigussie, 1988). The crop performs best in altitudes ranging from 2200 to 2800 meters above sea level (m. a. s. l.). Linseed grows well within temperature ranges of 10 to 30°C; but it performs best between 21 to 22°C. Optimum soils for linseed are well drained but moisture retentive and medium to heavy textured such as clay loams and silty clays. Linseed will not perform well on soils with pH less than 5 and above 7 and is sensitive to soil salinity (Adugna, 2007), water logging or heavy clay soils (Jacobsz and van der Merwe, 2010) and seed bed conditions (Alexopoulou and Christou, 2011). It is widely cultivated in the high elevations area of Arsi, Bale, Shewa, Gojam, Gonder, Wollo and Wellega

(Getinet and Nigussie, 1997).

Linseed oil is suitable for human consumption, and is used as a nutritional supplement. It is rich in omega-3 fatty acids, especially alpha-linolenic acid (C18:3) that is beneficial for heart disease, breast cancer, prostate cancer, colon diseases, inflammatory bowel disease, arthritis and a variety of other health conditions. It also contains a group of chemicals called lignans that play a significant role in the prevention of cancer (Budwing, 1994). The meal, which remains after oil extraction, is a valuable feed to animals as a protein supplement (Getinet and Nigussie, 1997). There is also a growing demand in the world market for linseed due to its numerous health benefits, especially in Europe (Wijnands *et al*., 2007). However, opportunities for oilseeds export are not fully exploited yet because of low productivity, inadequate quality, improper post-harvest handling, poor infrastructure and poor market information.

The Ethiopian edible oil sector consists of two groups of producers: the local, small-scale processors (>1000) and a few medium and large scale enterprises (~20). The entire sector produces approximately 20,000 tons of edible oil annually; while domestic demand is estimated at 200,000 tons. Consequently, Ethiopia imports up to 160,000 tons of edible oil annually and this figure is increasing every year (PPPO, 2009). The increase of import suggests a potentially large domestic market. Main edible oil imports are palm and soybean oils from Malaysia and Indonesia. Ethiopia imported 351 thousand MT of palm oil by expending 424 million US Dollar in 2015 (USDA, 2015). Substitution of these oils by domestic production is encouraged by high domestic prices. Export oil (like sesame and linseed) is hardly being produced locally, since the export price of seed is usually very attractive and sesame seed is hardly locally consumed (PPPO, 2009). It can be seen as a business opportunity to increase the local capacity to produce linseed and sesame oils for export, increasing added value, foreign exchange and employment opportunity. In order to improve the Ethiopian edible oil sector, the Government should create equal taxation system for both domestically produced and imported edible oils, undertake feasibility study for increased production of oilseeds, and develop good manufacturing practices for the Ethiopian mill sector.

Despite the wide values of linseed in terms of nutritional, industrial, and export earnings; productivity and production of linseed is certainly low, 1.094 t/ha (CSA, 2017) as compared to cereal and pulse crops. Currently, there is a huge shortage of edible oil in the country (PPPO, 2009). Hence, concerted research, development, promotion, infrastructure and policy intervention efforts are needed, at all levels, in order to reverse the current situations. This paper presents the overall performances of the recently developed and released linseed variety (*Yadanno*) with the aim to play a significant role in solving the chronic edible oil shortage in the country, and to exploit its linseed production and productivity capacity for domestic uses and export purposes.

VARIETAL EVALUATION

Yadanno (H31 X Belay-96-208) was derived through hybridization between *Belay-96* and H31 (a promising selection obtained from Holetta Agricultural Research Center/HARC). After crossing, F generations (F_2 to F_5) of linseed crosses had been screened on artificially developed wilt (*Fusariumoxysporumf.sp. lini*) sick plots in order to select and advance lines with good agronomic performances and diseases resistance. As *Yadanno* outperformed several linseed lines, previous varieties, selections and accessions in observation and preliminary yield trials, it was advanced to regional variety trial to be tested across representative locations over years in order to further test its overall performances. The linseed regional variety trial set II consisting 18 linseed lines along with the standard check (*Kulumsa-1*) and the local check was conducted at major linseed growing districts of Arsi and West Arsi Zones including Kulumsa (Tiyo District), Bekoji (Lemu & Bilbillo District), Asasa (Gedab Asasa District) and Kofele (Kofele District) for three main growing seasons (2010/11 to 2012/13). In these locations, the altitude ranges from 2200 m. a. s. l. (Kulumsa) to 2780 m. a. s. l. (Bekoji), and average annual rainfall ranges from 620 mm in Asasa to 1100 mm in Bekoji. The genotypes were tested across four locations in RCB design with four replications. Plot size was six rows of 20 cm apart and 5 m long. A seed rate of 25 kg ha-1 and fertilizer rate of 23/23 kg ha-1 N/P2O5 was applied at planting at each location, except at Kulumsa where fertilizer was not applied to minimize lodging. Other recommended cultural practices were also applied. Necessary agronomic performances and disease reactions were recorded.

AGRONOMIC AND MORPHOLOGICAL CHARACTERISTICS

In an attempt to develop *Yadanno*, higher seed yield, oil content and resistance to major linseed diseases were important traits of consideration. *Yadanno* flowered within 82 days and matured within155 days after emergence (Table 1). *Yadanno* and *Kulumsa-1*are similar in terms of maturity regime. *Yadanno* was highly uniform and its average height was 88 cm, but *Kulumsa-1* was 97 cm tall, implying better resistance of *Yadanno* to lodging. Both *Yadanno* and *Kulumsa-1*are brown and bold seeded. The average weight of 1000-seeds was 6.4 g for *Yadanno*, which is greater by 14.3% and 25.5% better than that of *Kulumsa-1* and the local check, respectively (Table 2 & 3). *Yadanno* is a variety suitable for rain-fed, low inputs and organic farming on different soil types as long as the pH value is within the range of 6.0 to 7.6. However, it is not suitable for water logged or poorly drained soils.

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A summary of agronomic and morphological characteristics of the variety are presented in Table 1.

Table 1. Agronomic and morphological characteristics of *Yadanno* linseed variety

Adaptation area	
Altitude (m. a. s. l.)	2000-2800
Rainfall (mm)	600-1100
Temperature (^{O}C)	9.5-23.0
Soil pH	6.0-7.6
Fertilizer rate	
N (kg ha-1)	23
P_2O_5 (kg ha-1)	23
Planting date	Early to late June
Seed rate (kg ha-1)	
Row planting (20 cm between rows)	25
Broadcasting	35-40
Days to flowering	82
Days to maturity	155
Plant height (cm)	88
Number of pods per plant	44-77
Seed color	brown
Weight of 1000 seeds (g)	6.4
Reaction to major diseases	<1.0 (Resistant)
Oil content (%)	39.1
Seed yield (kg ha-1) at research stations	2246
Seed yield (kg ha-1) on farmers' fields	1680
Year of release	2015
Breeder/Maintainer	Kulumsa Agri. Research Center

YIELD PERFORMANCE

Considering the overall seed yields, *Yadanno* (H31 X Belay-96-208) produced better seed yield (2246 kg/ha) than the standard check *Kulumsa-1*(1772 kg/ha) across locations (Table 2 & 3). This variety consistently performed better than the checks over three years. *Yadanno* was 26.7% high yielder than the standard check (*Kulumsa-1*) and 44.5% high yielder than the local check. It had 30% oil yield and 2.4% oil content advantage over *Kulumsa-1*. Likewise, it had 55% oil yield and 7.1% oil content advantage over the local check. It was highly uniform with strong stalk and resistant to lodging and showed noble competence with different weed species.

Table 2. Mean agronomic performance and diseases reaction of 20 linseed genotypes tested in four locations in Arsi and West Arsi Zones in the years, 2010/11-2012/13

Plot	Treatments	Days to Flower	Days to Mature	Diseases (0-5 scale) P. mildew	Diseases (0-5 scale) Pasmo	Diseases (0-5 scale) Wilt	Plant height (cm)	TSW (g)	SY (kg/ha)	OC (%)	OY (kg/ha)
1	H31 X Belay-96-194	77	155	0.4	0.4	0.4	89	6.6	2226	38.7	861
2	H31 X Belay-96-159	79	154	0.4	0.4	0.4	88	6.6	2053	39.1	803
3	H31 X Belay-96-18	82	157	0.4	0.2	0.5	90	6.4	1920	39.1	751
4	**H31 X Belay-96-208**	**82**	**155**	**0.5**	**0.7**	**0.5**	**88**	**6.4**	**2246**	**39.1**	878
5	H31 X Belay-96-216	80	155	0.5	0.7	0.4	90	6.3	1882	38.0	715
6	H31 X Belay-96-146	82	157	0.5	0.3	0.4	90	6.2	2134	39.1	834
7	H31 X Belay-96-215	79	155	0.4	0.2	0.4	91	6.7	2044	38.4	785
8	H31 X Belay-96-204	79	155	0.3	0.3	0.4	89	6.5	2084	37.6	784
9	H31 X Belay-96-210	82	156	0.5	0.4	0.5	92	6.2	1825	38.0	694
10	Tolle X Chilallo-112	81	155	0.6	0.5	0.4	95	6.5	1968	38.1	750
11	H31 X Belay-96-201	80	156	0.5	0.3	0.5	92	6.4	1862	38.0	708
12	H31 X Belay-96-198	85	156	0.5	0.3	0.4	93	6.2	1975	38.0	751
13	H31 X Belay-96-236	78	154	0.7	0.8	0.3	84	6.3	2087	37.6	785
14	H31 X Belay-96-127	82	157	0.4	0.3	0.5	87	6.6	2018	38.5	777
15	H31 X Belay-96-50	81	158	0.4	0.4	0.4	88	6.5	2021	37.9	766
16	H31 X Belay-96-234	80	156	0.5	0.3	0.6	88	6.7	1916	39.1	749
17	H31 X Belay-96-73	79	154	0.4	0.3	0.5	91	6.6	2111	38.8	819
18	H31 X Belay-96-141	80	154	0.4	0.2	0.4	91	6.5	2007	38.8	779
19	Kulumsa-1	88	156	0.4	0.4	0.6	97	5.6	1772	38.2	677
20	Local check	88	158	1.1	0.9	0.7	86	5.1	1554	36.5	567
	Mean	**81**	**156**	**0.5**	**0.4**	**0.5**	**90**	**6.3**	**1985**	**38.3**	**761**
	LSD(0.05)	1.18	1.52	0.14	0.17	0.2	2.33	0.21	167.8		
	CV(%)	2.2	1.6	39.0	67.9	65.1	5.3	0.1	14.8		

Where, P. Mildew = Powdery mildew; TSW = 1000 seeds weight; SY = Seed yield; OC = Oil content; OY = Oil yield; LSD = Least significant difference; CV = Coefficient of variation

Table 3. Summary of pooled mean seed and oil yields, other data and diseases reaction of *Yadanno* and the checks across years and locations

Plot	Treatments	DF	DM	PM (0-5)	Pasmo (0-5)	Wilt (0-5)	PH (cm)	TSW (g)	SY (kg/ha)	OC (%)	OY (kg/ha)
1	***Yadanno***	**82**	**155**	**0.5**	**0.7**	**0.5**	**88**	**6.4**	**2246**	**39.1**	878
2	*Kulumsa-1*	88	156	0.4	0.4	0.6	97	5.6	1772	38.2	677
3	Local check	88	158	1.1	0.9	0.7	86	5.1	1554	36.5	567

Where, DF = Days to flower; DM = Days to mature; PM = Powdery mildew; PH = Plant height; TSW = 1000 seeds weight; SY = Seed yield; OC = Oil content; OY = Oil yield

STABILITY PERFORMANCE

Yield stability in 18 lines of linseed was studied for three years (2010/11 to 2012/13) at four locations (Kulumsa, Bekojji, Asasa and Kofele) using different stability parameters such as (*bi*) the regression coefficient (Finlay and Wilkinson, 1963), (S2di) deviation from regression (Eberhart and Russel, 1966), ecovalence (Wricke, 1962), Shukla stability variance (Shukla, 1972), *CV* = coefficient of variation (Francis and Kannenberg, 1978) and a superiority measure (Lin and Binns, 1988) as shown on Table 4. The stability of varieties was defined by high mean seed yield, regression coefficient (*bi* = 1.0) and deviations from regression (S2di = 0). Besides, low CV, ecovalence, Shukla stability variance, superiority measure reveal that a variety is stable across tested environments.

The results of the study showed that *Yadanno* and *Kulumsa-1* were stable linseed variety based upon different stability parameters (Table 4). Likewise, *Yadanno* was the best variety in terms of mean seed and oil yields.

Table 4. Summary of overall yield (kg/ha) and joint regression and other stability parameters of 20 linseed genotypes evaluated in South Eastern Ethiopia in 12 environments, 2010/11-2012/13

GEN	Mean	Francis CV(%)	Eberhart&Russell Bi	S2di	Shuckla ri2	Wricke'sEcovalence Wi	Superiority Measure Pi
1	2226.156	22.0622	0.822	37042.72	63793.34	413745.2	35648.49
10	1968.375	22.795	0.8253	-11275.1	17414.73	121560	129216.4
11	1861.5	26.1594	0.8773	1324.041	24560.22	166576.6	179976.1
12	1975.406	31.8844	1.1005	41862.19	61606.68	399969.3	131338.9
13	2086.906	31.8603	1.2289	-3881.95	31331.92	209238.3	79660.32
14	2018.438	35.7419	1.325	6641.041	58065.95	377662.7	109476.9
15	2021.313	27.9357	1.0529	-15174.9	4992.89	43302.42	101498.5
16	1915.625	28.4956	0.9034	56979.74	75766.61	489176.9	199868.8
17	2110.844	24.3763	0.9037	18040.16	38662.11	255418.5	82696.09
18	2006.594	26.6583	0.9928	-12763.1	6426.7	52335.42	104530.6
19	**1772.375**	**32.8563**	**1.064**	**733.9087**	**20550.98**	**141318.4**	**241439.4**
2	2053.469	27.4423	1.017	7813.128	26097.91	176264	83157.88
20	1554.25	36.1901	1.0178	5930.064	24313.03	165019.3	406856
3	1920.156	26.1703	0.8873	13412.86	35328.09	234414.2	145824
4	**2245.656**	**23.3553**	**0.9255**	**16884.08**	**36387.49**	**241088.4**	**25596.1**
5	1882.313	29.9379	1.0017	18037.39	35745.07	237041.2	169375.1
6	2133.906	30.7775	1.1971	9071.356	39405.09	260099.3	64090.39
7	2043.656	30.1471	1.1351	-3677.24	20801.76	142898.3	103498.5
8	2084.344	23.8659	0.8907	5502.218	27556.06	185450.4	76993.66
9	1824.938	25.3948	0.832	777.9094	28176.71	189360.5	203829.9

Where, GEN = the 20 linseed genotypes evaluated, Mean = average yield of the 20 linseed genotypes,
Bi = regression coefficient, *S2di* = deviation from regression (Eberhart and Russell 1966),
CV = coefficient of variation (Francis and Kannenberg, 1978), r*i*2 = Shukla stability variance (Shukla 1972), *Wi* = ecovalence (Wricke, 1962) and Pi = superiority measure (Lin and Binns, 1988).

DISEASE REACTION

On the standard rating scale of 0-5, 0 being highly resistant, and 5 highly susceptible, *Yadanno* scored mean of 0.5, 0.5 and 0.7 for wilt (*Fusariumoxysporium*), powdery mildew (*Oidium sp.*) and pasmo (*Septoria linicola*) diseases, respectively (Table 2), indicating that the variety is resistant to major diseases of linseed. The resistance reaction of the variety could be integrated with other disease management methods such as crop rotation, managing infested debris, and fungicide seed treatments for remarkable results.

QUALITY ANALYSIS

Typically, linseed consists of approximately 40% fat, 28% dietary fiber, 21% protein, 4% ash and 6% carbohydrates such as sugars, phenolic acids, lignans, and hemi-cellulose (Vaisey-Genser and Morris, 2010). Linseed is rich in polyunsaturated fatty acids, particularly alpha-linolenic acid (ALA), the essential omega-3 fatty acid, and linoleic acid (LA), the essential omega-6 fatty acid. These two polyunsaturated fatty acids are essential for humans-that is, they must be obtained from the fats and oils in foods because our bodies cannot make them. The omega-3 fatty acids have many biological effects that make them useful in preventing and managing chronic conditions such as type 2 diabetes, kidney disease, rheumatoid arthritis, high blood pressure, coronary heart disease, stroke and certain types of cancer (Connor, 2000). The composition of linseed can vary with genetics, growing environment, seed processing and method of analysis (Daun, *et al*., 2003). The protein content of the seed decreases as the oil content increases (Daun and Declercq, 1994). The oil content of linseed can be altered through traditional breeding methods, and it is affected by geography. Linseed requires moderate to cool temperatures and adequate moisture during the growing season for optimum seed yield and quality. Good yield can be achieved with a temperature range of 10-30^{o}C, and a mid-day relative humidity of 60-70%, and a rainfall of 150-200 mm distributed over the growing periods. Extensive scientific research over the past few decades has revealed numerous nutritional benefits of linseed due primarily to its fat, lignan, dietary fiber, and protein contents.

In the present study, the results of laboratory tests (Table 2 & 3) indicated that *Yadanno* contained 39.1% oil content and it had 30% oil yield and 2.4% oil content advantages over *Kulumsa-1*. Likewise, it had 55% oil yield and 7.1% oil content advantages over the local check. Besides, *Yadanno* had 14.3% and 25.5% more 1000 seeds weight than *Kulumsa-1*(the standard check) and the local check, respectively. Furthermore, *Yadanno* is also rich in essential fatty acids, lignan, fiber and protein. Hence, *Yadanno* has better health, industrial, nutritional and feed values.

CONCLUSIONS

Yadanno was the best yielding linseed variety. It is stable in seed yield performance over locations and years. It was resistant to major diseases of linseed that prevailed in the growing areas. *Yadanno* produced higher seed and oil yields and contained better oil content. Farmers also preferred the variety for its overall superior performance over the existing local variety, which is manifested by high uniformity, tall plant height, firm stalk, better pods load and number of branches per plant. Likewise, the variety has better industrial, non-industrial and nutritional values. Hence, *Yadanno* was verified and officially released for large scale production in Arsi, West Arsi Zones and similar agro-ecologies of Ethiopia.

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