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African Journal of Plant Science

Full Length Research Paper

Evaluation of wheat genotypes (*Triticum aestivum* L.) for yield and yield characteristics under low land area at Arba Minch, Southern Ethiopia

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The objective of this research was to evaluate wheat genotypes for yield and yield characteristics under the low land area of Arba Minch, Southern Ethiopia. A field experiment was conducted with 27 bread wheat genotypes in a randomized complete block design with two replications at Amibara Farm, Arba Minch from March to June 2020. Varieties differed significantly (p<0.01) for the yield related characters and yield. The major findings include identification of varieties with earliest heading and physiological maturity, highest number of effective tillers formed, ear length and spikelets in the ear, grains in ear and spikelet, thousand grains weight, and grain yield. It could be concluded that varieties, Lucy, Fentale-1, Amibara-2, Alidoro, Ogolcha, Daka, Fentale-2, Ga'ambo, Amibara-1 and Werer-2 were high yielding under lowland area at Arba Minch. It is recommended that these varieties should be further tested for identification and selection of high yielding ones for lowland areas in Southern Ethiopia.

Key words: Bread wheat, varieties, yield characteristics, grain yield, lowland, Ethiopia.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important cereal crop of the family Poaceae (Gramineae) and is the second most important staple food crop after rice grown in 89 countries comprising temperate, subtropical and tropical climates. It was cultivated in more than 221 million hectares of land producing 728.9 million tonnes of food grains with a productivity of 36.2 q/ha in the world (FAO, 2014). It is the staple food of about 35 percent of the world's population (Nanda and Agrawal, 2008). Bread wheat (*T. aestivum* L.*)* grain contains gluten protein which makes it suitable to prepare leavened bread, pita bread, *chapati, Naan, ambassa*, cake and other food recipes. It is an important source of carbohydrates (68%), proteins (13%), minerals, and vitamin B and E. It provides 19% of the total calories in human food in the world, which is higher than other food sources (FAO, 2014). It is also used as animal feed and its straw as fodder for cattle, house thatching, manufacturing paper, cardboard, and several handicraft items.

Ethiopia ranks first in wheat production followed by Sudan and Kenya in East Africa, and second in sub-Saharan Africa after South Africa (FAO, 2015). It is the third largest produced cereal crop after maize and teff (*Eragrostis tef*) in Ethiopia. Wheat is grown >1500 m.a.s.l.

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in mid and highland areas as a rain-fed crop in Ethiopia. Irrigation contributes 1.1% of the total cultivated land (Girmay, 2017). At mid and highlands between1900 m.a.s.l. and 2700 m.a.s.l., wheat was grown in 1.696907 million hectares during 2017-18 and produced about 46.429657 million tonnes with average productivity of 27.3 q/ha in Ethiopia (Anonymous, 2018); whereas the world average productivity was 33 q/ha (EIAR, 2020). Bread wheat demand in Ethiopia is increasing because of the preference of people to use it for food as a major source of energy and protein (Hailu, 2003) and it accounts for about 65% of the total wheat area (Alemayehu et al., 2011). The remaining area is under durum and emmer (*Aja*) wheats. There is a shortage of wheat production in the country for meeting the demand. According to Gebre et al. (2017), about 1.0 million tons of wheat is being imported annually since 2008 in Ethiopia at the cost of 500 million US dollars. Lately, Ethiopia imported 1.7 million tonnes of wheat (EIAR, 2020).

Wheat production can be scaled up by developing short duration, heat and stress tolerant varieties under lowland areas (< 1500 m). Studies conducted at Werer Agricultural Research Centre of the Ethiopian Institute of Agricultural Research (EIAR) had indicated that wheat grain yield of above 40.0 q/ ha could be obtained in lowland irrigated areas (Mohammad, 1994). Wheat production has to be increased by expanding the cultivation of wheat in low land areas with high temperatures and different types of soils (Bayisa et al., 2019). There are prospects of wheat production in irrigated lowland around lakes, Abaya and Chamo at Arba Minch and Omo river valley, Southern Ethiopia and 12 river basins in Ethiopia (Amanuel et al., 2018). Information based on studies to evaluate wheat genotypes in lowland areas in Southern Ethiopia is lacking. The present investigation was undertaken with the objective of evaluating bread wheat genotypes for yield and yield characteristics under lowland irrigated areas at Arba Minch, Southern Ethiopia.

MATERIALS AND METHODS

Description of the study area

Study area is located at 6°3'37 N latitude, 37°33' E longitude and is low land at 1202 m elevation above mean sea level at Amibara Farm, Arba Minch irrigated from Kulfo River water. The experimental field was nearly level with 0.5 to 2% slope and 0.3 to 1.1 degrees. Soil characteristics of the field were determined from a composite sample made by mixing 5 random soil samples drawn from 0 to 15 cm depth following standard procedures. The proportions of sand, silt and clay particle sizes in the soil were 9, 39 and 52%, respectively with overall textural class as clay. The pH of the soil was neutral (6.8). The organic matter (OM) and total nitrogen (TN) contents were 1.93 and 0.09%, considered as low and medium, respectively (Tekalign, 1991). The carbon nitrogen ratio (C/N) of 12 was fairly good. The available phosphorus (P) and potassium (K) were 34.2 and 269 ppm, and are considered as very high (Olsen et al., 1954). The cation exchange capacity (CEC) of 56.86 centimol per kg was very high (>40). The concentration of exchangeable cations, Ca, Mg, Na, and K being 40.23, 8.27, 0.44 and 0.93 centimol per kg, respectively; and the cation exchange capacity (CEC) of 56.86 Centimol per kg were very high. The overall base saturation (BS) of 88% was very high (>80) according to Hazelton and Murphy (2007). Based on OM and TN contents, the soil appeared to be not adequately fertile. However, other parameters, C/N ratio, available P and K, exchangeable bases, CEC and BS indicated that the soil was fertile.

Weather conditions during the study

The mean monthly maximum temperatures during March, April, May and June, the wheat cropping period were 33.16, 31.31, 31.05 and 30.24°C. The mean minimum temperatures during these months were 18.18, 17.84, 18.54 and 17.86°C. The total rainfall during March, April, May and June was 167.5mm, 263.2, 127.1 and 82.5mm, respectively; but it was not evenly distributed. The mean monthly relative humidity percent during March, April, May and June was 57.20, 65.04, 64.53 and 63.85 percent, respectively. The mean sunshine hours during March, April, May and June were 8.61, 6.2, 7.06 and 6.2 h, which were fairly adequate for the growth of wheat crop.

Materials and experimental design

The materials for the study consisted of 27 wheat genotypes/varieties, namely, Amibara-1, Amibara-2, Fentale-1, Fentale-2, Ga'ambo, Lucy, Werer-2, Alidoro, Biqa, Daka, Dashen, Dereselign, Enkoy, ET 13A2, Hawi, Hidase, Hoggana, Honqolo, Kakaba, Kingbird, Kubsa, KBG-01, Millenium, Ogolcho Pavone-76, Shorima and Wane. The seeds of the varieties were collected from Agricultural Research Centers (ARC) at Werer and Kulumsa of the Ethiopian Institute of Agricultural Research in February 2020. The field experiment with 27 genotypes/treatments was laid out in a randomized complete block design with two blocks/replications with a seed rate of about 100 kg/ha. The plot size for each treatment was 6 rows of 3 m, with space between rows of 30 cm.

Experimental procedure

Field preparation

The field was ploughed by tractor and left for drying for 15 days in February followed by harrowing/disking 3 times and ditching for making water channels. Pre-sown irrigation was given for preparation of the field with adequate moisture.

Fertilizers and chemicals application

Blended fertilizer, NPSB (18.9% N:37.7 % P_2O_5: 6.97% S: 0.1% B) was applied at 150 kg per hectare as basal dose and Urea (46%N) at 150 kg per hectare in two split doses at tillering and shooting stages as per fertilizer recommendation for wheat production under low land in Ethiopia (Anonymous, 2015). The total nutrients applied through fertilizers were 97.35 kg/ha N, 56. 55 kg/P_2O_5, 10.45kg/ha S and 0.15 kg B. The fungicides, "Progress- Propiconazole" and "Nativo-Trifloxystrobin+ Tebuconazole" were sprayed at 0.5 and 1.0 l/ha on wheat crop at tillering and heading stages to control leaf rust disease. The insecticides, "Ferrate" and "Diazinone" were sprayed at 0.5 and 1.0 l/ha at heading and grain development stages to control stem borer and termites.

Table 1. Analysis of variance for characters with F-value and probability.

Character	Varieties		Blocks	
	F-value	Probability	F-value	Probability
Days to heading	33.32	<.01	3.04	0.09
Days to ph. Maturity	34.57	<.01	1	0.32
No. of effective tillers	15.41	<.01	7.79	<.01
Plant height	28.11	<.01	0.22	0.63
Ear length	12.02	<.01	1.13	0.29
No. of spikelets in ear	25.29	<.01	0.48	0.49
No. of grains in ear	36.22	<.01	2.81	0.10
No. of grains in spikelet	5.9	<.01	0.39	0.53
Thousand grain weight	19.24	<.01	1.4	0.24
Grain yield	155.08	<.01	0.66	0.24

Days to ph. Maturity = Days to physiological maturity

Irrigations and weeding

Besides the receipt of irregular uneven distributed total rainfall of 621.3 mm during the wheat crop period from March to June 21, 2020, when the soil of the experimental field was dry, four supplementary irrigations were given with flowing water at the coronal/nodal root initiation stage on March 28, tillering stage on April 10, shooting/ heading stage on May 15 and grain development stage on May 21, 2020. Weeding, hoeing and tying of wheat plants were done manually when required beginning from germination to the harvesting of the crop in June 2020.

Data collection

Data were collected on 9 yield-related characters and the grain yield, namely, days to 50% heading or spike emergence and days to 90% physiological maturity from the sowing date, plant height (cm) on ten random plants, number of effective or productive tillers per square meter in net plot, ear/spike length (cm) on ten random plants per plot, number of spikelet in ear/spike and number of grains per ear and per spikelet on ten random plants, and thousand grains weight (g) and grain yield (g) adjusted to 12.5 % moisture content per plot and converted to quintal per hectare (q/ha).

Data analysis

Data were subjected to analysis of variance for the characters in randomized complete block design following SAS – Version 9.00 (2004). Means were compared with least significant difference at 5% level of probability.

RESULTS AND DISCUSSION

The results on yield characteristics and yield of wheat varieties at Arba Minch 2020 are presented in the following sections. The analysis of variance for the characters with F-value and probability is presented in Table 1.

Days to heading

Varieties differed significantly ($p<0.01$) for the number of days to heading (DH) or spike emergence which varied from 40 to 74 days with the mean of all varieties 60.61 DH (Table 2). The earliest heading was recorded in 40 days in variety Dereselign, which was significantly different from other varieties. The second earliest heading occurred in 51 days in variety Wane, which also differed from other varieties. The next earlier heading varieties were Fentale-2, Kakaba, Biqa, Amibara-1, Fentale-1, Hawi, Hidase, KBG-01, Pavone-76, Amibara-1, Enkoy, and Ogolcho (54.5 to 59.5 DH). Varieties taking more days to heading than the mean of all varieties were Daka, Kingbird, Ga'ambo, Alidoro, Shorima, Werer-2 and Honqolo. The late heading varieties were Millenium, Dashen, Lucy and Kubsa with the latest ones, ET-13 A2 and Hoggana, taking 74 days. As in the present studies, significant differences among genotypes for DH were recorded at Werer Agricultural Research Centre (WARC) under low land irrigated conditions (Gebre et al., 2017; Bayisa et al., 2019). In comparison, variety Werer took 5 more days (63DH) at Arba Minch than that at Werer (Bayisa et al., 2019). The early heading at WARC could be due to higher monthly maximum and minimum temperature (38.06 and 21.06°C) than at Arba Minch (31.44 and 18.10°C) during the crop season. Early heading in wheat varieties had also been observed under drought and heat stress than irrigated conditions in Nepal (Poudel et al., 2020).

Days to physiological maturity

Varieties differed significantly ($p<0.01$) for number of days to physiological maturity (DPM) ranging from 72 to 106 days with mean of all varieties 91.5 DPM (Table 2). Variety Dereselign was earliest to physiologically mature at 72 days changing colour of leaves, peduncles and ears/spikes from green to yellow of 90% of the plants from the sowing. At this stage, the grains are fully developed and lose connection for the supply of photosynthetic

Table 2. Average number of days to heading (DH) and physiological maturity (DPM), number of effective tillers (NET) m^{-2} and plant height (PH) in cm of wheat varieties at Arba Minch during 2020.

Variety	DH	DPM	NET	PH
Amibara-1	58^{hij}	92.5^{fghij}	401.5^{fghij}	78.7^{efg}
Amibara-2	56^{ij}	$89.5^{jk}l^{m}$	392^{ijk}	75.8^{fgh}
Fentale-1	56^{ij}	$90^{jk}l^{m}$	397^{hij}	71.6^{hijk}
Fentale2	54.5^{jk}	$89^{k}l^{m}$	437^{cd}	73^{hij}
Ga'ambo	63.5^{def}	$91.5^{ghijk}l$	393^{ijk}	81^{de}
Lucy	69^{b}	93.5^{fgh}	432^{cde}	82.4^{de}
Werer-2	63^{efg}	$91.5^{ghijk}l$	504.5^{a}	73.8^{hij}
Alidoro	65^{def}	94^{fgh}	409.5^{efghi}	83.9^{cd}
Biqa	55.5^{j}	$88.5l^{m}$	408.5^{efghi}	79.95^{def}
Daka	61.5^{fgh}	95^{ef}	420^{defgh}	81.4^{de}
Dashen	67.5^{bc}	97.5^{de}	$363l^{m}$	75.1^{ghi}
Dereselign	40.0l	72p	440^{bcd}	90.75^{b}
Enkoy	58^{hij}	$90^{ijk}l^{m}$	395.5^{hijk}	87.7^{bc}
ET-13A2	74^{a}	106^{a}	$380^{jk}l$	96.5^{a}
Hawi	57^{ij}	$91^{hijk}l$	$388^{ijk}l$	$69.9^{jk}l^{m}$
Hidase	57.5^{ij}	$87.5^{m}n$	454^{bc}	$69.9^{jk}l^{m}$
Hoggana	74^{a}	104^{ab}	$364.5l^{m}$	$69.8^{jk}l^{m}$
Honqolo	66.5^{bcde}	99^{cd}	424.5^{def}	59.6n
Kakaba	54.5^{jk}	82o	464.5^{b}	71.9^{hijk}
Kingbird	62^{fg}	92^{fghijk}	390^{ijk}	$71.1^{ijk}l$
Kubsa	69^{b}	101^{bc}	445^{bcd}	$70.9^{ijk}l^{m}$
KBG-01	56^{ij}	84.5no	$371.5^{k}l^{m}$	$68^{k}l^{m}$
Millenium	67^{bcd}	94.5^{efg}	425^{def}	74.9^{ghi}
Ogolcho	59.5^{ghi}	$89.5^{jk}l^{m}$	423^{defg}	81.3^{de}
Pavone-76	57^{ij}	$90^{ijk}l^{m}$	395.5^{hijk}	$70.3^{jk}l^{m}$
Shorima	63.5^{def}	93^{gfhi}	352^{m}	$66.7l^{m}$
Wane	51^{k}	84.5no	398.5^{ghij}	66.5^{m}
Mean	60.61	91.5	410	75.63
SE(±)	1.26	1.15	8.68	1.54
LSD 5%)	3.68	3.35	25.25	4.48
CV	2.96	1.78	2.99	2.88
P	<0.01	<0.01	<0.01	<0.01

Values in a column with same letter in superscript are not significantly different at 5% probability level.

assimilates, nutrients and water from the tissues of the ovary of the mother plants. The other earlier maturing varieties were Kakaba, KBG-01 and Wane taking 82-85 days. The next early maturing varieties were Hidase, Biqa, Fentale-2, Amibara-2, Ogolcho, Fentale-1, Pavone-76 and Enkoy, which took 88 to 90 days. Varieties with mid maturity period (91-93days) around the mean of all varieties were Hawi, Ga’ambo, Werer-2, Kingbird, Amibara-1, Shorima, Lucy, Alidoro, Millenium and Daka. The late maturing varieties were Dashen, Honqolo, Kubsa and Hoggana along with latest maturity in variety, ET-13A2 (106 DPM). As in the present studies, significant differences for days to physiological maturity among genotypes were found at WARC (Gebre et al., 2017; Bayisa et al., 2019). Varieties, Fentale and Werer matured 8 days later at Arba Minch than that at WARC. It could plausibly be due to about 7 and 3°C less mean maximum and minimum monthly temperatures (31.44 and 18.1°C) at Arba Minch than that at Werer (38.06 and 21.06°C) during the cropping season. It is known that lower temperatures delay growth and maturity in plant species and thus the difference in days to maturity of varieties at Arba Minch and Werer in Ethiopia. Similarly, wheat varieties matured late in irrigated conditions than that in drought and heat stress environments in Nepal (Poudel et al., 2020).

Number of effective tillers

Average numbers of effective or productive tillers per m^2 in wheat varieties are presented in Table 2, which varied from 504.5 to 352 m^{-2} with the mean of all varieties 410 m^{-2}. Varieties differed significantly ($p<0.01$) for number of productive tillers per m^2. Highest number of effective tillers (504.5 m^{-2}) was produced in variety Werer-2. The second highest tillers were formed in variety Kakaba (464.5 m^{-2}) followed by varieties Hidase, Kubsa, Dereselign, Fentale-2 and Lucy. The third group of varieties producing high effective tillers (425to 401.5 m^{-2}) were Millenium, Honqolo, Ogolcho, Daka, Alidoro, Biqa and Amibara-1. Other varieties forming productive tillers less than the mean of varieties were Wane, Fentale-1, Enkoy, Pavone-76, Ga'ambo, Amibara-2, Kingbird, Hawi and ET-13A2. The lower effective tillers were formed in varieties KBG-01, Hoggana and Dashen with lowest in Shorima (352 m^{-2}). In line with the present studies, significant differences among genotypes/varieties for number of effective tillers were reported by other researchers (Raza et al., 2018; Bayisa et al., 2019).

Plant height

Varieties differed significantly ($p<0.01$) for plant height, which varied from 59.6 to 96.5 cm (Table 2). Highest plant height (96.5cm) was recorded in variety ET-13 A2. The next higher plant height was in varieties Dereselign and Enkoy. These three wheat varieties with plant height range between 86 cm and 100 cm could be categorized as a double dwarf. The plants of variety, Enkoy, with an average height of 87.7 cm lodged affecting its yield. Wheat genotypes/varieties with plant height between 101-and 115 cm are categorized as a single dwarf (Ram, 2011). The plant height in the remaining 24 varieties was less than 85 cm (Ram, 2011).

There were significant differences among the triple dwarf varieties. Varieties Alidoro, Lucy, Daka, Ga'ambo, Ogolcho, Biqa and Amibara-2 had higher plant height (83.9 -78.7 cm). The other triple dwarf varieties with plant height around and less than the general mean were Amibara-2, Dashen, Millenium, Werer-2, Fentale-2, Kakaba and Fentale-1. The shorter plant height from 71.1 to 66.5 cm was recorded in varieties Kingbird, Kubsa, Pavone-76, Hawi, Hidase, Hoggana, KBG-01, Shorima and Wane, with the shortest plant height of 59.6 cm in variety Honqolo. As in this study, significant differences among genotypes/ varieties were found at WARC (Gebre et al., 2017; Bayisa et al., 2019). However, it may be mentioned that the plant height in varieties Werer, Amibara, Fentale and Amibara at Arba Minch was 11 to 21 cm more than that at WARC (Bayisa et al., 2019), which could plausibly be due to more time taken by these varieties at Arba Minch for growth and maturity.

Ear length

Varieties differed significantly ($p<0.01$) for ear or spike length which varied from 9.22 to 6.32 cm with mean of all varieties 7.97 cm (Table 3). Longest ear length (9.22 cm) was recorded in variety Alidoro, which was statistically on par with Amibara-1. Other varieties with longer ears were Biqa, Millenium, Fentale-1 Fentale-2, Dashen, Dereselign, Ga'ambo and Ogolcho (8.67 cm to 8.17 cm). Medium ear length was recorded in varieties Kubsa, Amibara-2, Hidase, KBG-01, Hawi, Hoggana, Daka, Shorima and Lucy (8.12 cm to 7.72 cm). Short ears were formed in varieties ET-13A2, Pavone-76, Kingbird, Kakaba, Werer-2 and Enkoy (7.57 to 7.30 cm). Shorter ears were produced in variety Honqolo (6.97 cm)-and the shortest ears in variety Wane (6.32 cm). As in the present study, significant differences among genotypes for spike or ear length were reported by other researchers (Gebre et al., 2017; Bayisa et al., 2019).

Number of spikelets in ear

Varieties differed significantly ($p<0.01$) for number of spikelets in ear or spike, which varied from 17.85 to 13.8 with mean of all varieties 15.51 (Table 3). Highest spikelets in ear (17.85) were formed in variety Millenium, followed by variety Lucy. The next higher spikelets in ear were produced in varieties Alidoro, Hoggana, Dashen and Ga'mbo, followed by Ogolcho and KBG-01 (17.15 to 16). The high number of spikelets was recorded in varieties Fentale-2, Biqa, Kubsa, Amibara-1, Fentale-1 and ET-13A2 (15.88 to 15.35). Small number of spikelets in ear was noted in varieties Honqolo, Dereselign, Daka, Amibara-2, Kakaba, Werer-2 and Enkoy (15.2 to 14.6). Further lower spikelets in ear were recorded in varieties Kingbird, Shorima, Hawi, and Hidase~~;~~ and the lowest in varieties Pavone-76 and Wane (13.95 and 13.8). As in the present studies, significant differences among genotypes for number of spikelets per ear were also reported by others (Gebre et al., 2017; Bayisa et al., 2019).

Number of grains in ear

Varieties differed significantly ($p<0.01$) for number of grains in the ear which varied from 40.9 to 20.4 grains with mean for all varieties 32.33 grains (Table 3). Highest number of grains in the ear was formed in variety Alidoro. Second higher grains in the ear were recorded in varieties Lucy, Millenium and Dashen (38.5 to 38.25). The next high grains in the ear were produced in varieties Honqolo, Ogolcho, Ga'ambo, Werer-2, KBG-01, Hoggana, Kingbird and Kubsa (36 to 34.1). Medium number of grains in ears around the general mean was formed in varieties Daka, Fentale-1, Biqa, Amibara-1, Fentale-2, Amibara-2 and Wane. Low grains in ear were

Table 3. Average ear length (EL) in cm and number of spikelets (NSE) and grains per ear (NGE) and number of grains per spikelet (NGS) in wheat varieties at Arba Minch during 2020.

Variety	EL	NSE	NGE	NGS
Amibara-1	8.75^{ab}	15.5^{fgh}	31.75^{hij}	2.04^{defg}
Amibara-2	8.1^{defghi}	15^{hijklm}	30.8^{ijk}	2.09^{defg}
Fentale-1	8.52^{bcde}	15.4^{fghi}	32^{ghi}	2.07^{def}
Fentale-2	8.52^{bcde}	15.85^{fg}	31.7^{hij}	2^{efg}
Ga'ambo	$8.32^{bcdefgh}$	16.8^{cd}	35.7^{de}	2.125^{bcdef}
Lucy	7.72^{ijklm}	17.45^{ab}	38.5^{b}	2.2^{abcde}
Werer-2	7.35^{lmn}	14.7^{jklm}	35.7^{de}	2.42^{a}
Alidoro	9.22^{a}	17.15^{bc}	40.9^{a}	2.38^{bc}
Biqa	8.67^{bc}	15.6^{fgh}	32^{ghi}	2.05^{defg}
Daka	7.82^{hijkl}	15.05^{hijkl}	33.25^{fgh}	2.2^{abcde}
Dashen	8.45^{bcdef}	16.95^{bcd}	38.25^{bc}	2.31^{abcd}
Dereselign	8.37^{bcdefg}	15.1^{hijk}	29.5^{jklm}	1.95^{efgh}
Enkoy	7.3^{mn}	14.6^{jklmn}	26^{no}	2.12^{cdef}
ET-13A2	7.57^{jklm}	15.35^{ghi}	20.4p	1.32^{i}
Hawi	7.97^{fghijk}	14.4^{mnop}	29.3^{klm}	2.05^{defg}
Hidase	8.07^{efghi}	14.2^{nop}	26.8^{no}	1.84^{gh}
Hoggana	7.92^{ghijk}	17^{bcd}	34.95^{def}	2.05^{defg}
Honqolo	6.97^{n}	15.2^{hij}	36^{bcd}	2.2^{abcde}
Kakaba	7.47^{klm}	14.85^{ijklm}	28^{lmn}	1.88^{fgh}
Kingbird	7.5^{klm}	14.55^{klmno}	34.8^{def}	2.39^{ab}
Kubsa	8.12^{defghi}	15.55^{fgh}	34.1^{efg}	2.18^{abcde}
KBG-01	8.05^{efghi}	16^{ef}	35.5^{def}	2.21^{abcde}
Millenium	8.6^{bcd}	17.85^{a}	38.5^{b}	2.18^{abcde}
Ogolcho	$8.17^{cdefghi}$	16.5^{de}	36^{bcd}	2.17^{abcde}
Pavone-76	7.57^{jklm}	13.95^{op}	27.5^{mn}	1.97^{efg}
Shorima	7.82^{hijkl}	14.45^{lmno}	24.5^{o}	1.69^{h}
Wane	6.32^{o}	13.8^{p}	30^{ijkl}	2.17^{abcde}
Mean	7.97	15.51	32.3	2.08
SE(±)	0.178	0.22	0.84	0.09
LSD(5%)	0.51	0.64	2.33	0.26
CV	3.12	2.02	3.51	6.28
P	<0.01	<0.01	<0.01	<0.01

Values in a column with same letter in superscript are not significantly different at 5% probability level.

found in varieties Dereselign, Hawi, Kakaba, and Pavone-76. Lower grains in the ear were recorded in varieties Hidase, Enkoy and Shorima; and the lowest grains in variety ET-13A2 (20.4 grains). As in the present set of varieties, the significant differences among genotypes for grain number per spike were reported by other researchers (Gebre et al., 2017; Bayisa et al., 2019).

Number of grains in spikelet

Varieties differed significantly ($p<0.01$) for number of grains in spikelet which varied from 2.42 to 1.32 with mean of all varieties 2.08 (Table 3). Highest number of grains per spikelet (2.42) was formed in variety Werer-2, which was statistically on par with varieties Kingbird, Alidoro, Dashen, KBG-01, Lucy, Daka, Honqolo, Kubsa, Millenium, Ogolcho and Wane (2.39 to 2.17). The low grains in spikelet were recorded in varieties Ga’ambo, Enkoy, Amibara-2, Fentale-1, Biqa, Hawi, Hoggana, Amibara-1, Fentale-2, Pavone-76, Dereselign and Kakaba (2.12 to 1.88). The lower grains in spikelet were recorded in varieties Hidase and Shorima, and the lowest in variety ET-13A2 (1.32 grains). As in the present study, the differences among genotypes for number of grains in spikelets have been reported by other researchers (Raza et al., 2018; Amanuel et al., 2018).

Table 4. Average thousand grain weight (TGW) in gm and grain yield (GY) in q/ha of wheat varieties at Arba Minch during 2020.

Variety	TGW	GY
Am^{i}bara-1	28.3^{hijk}	22.969^{f}
Am^{i}bara-2	30.7^{fgh}	27.051
Fentale-1	29.8^{fghij}	30.698^{b}
Fentale-2	34.8^{cde}	24.712^{de}
Ga'ambo	37.2^{bc}	24.561^{e}
Lucy	42.3^{a}	38.392^{a}
Werer-2	24.4^{mn}	22.792^{f}
Al^{i}doro	33.3^{def}	27.018^{c}
B^{i}qa	25^{klm}	19.807^{g}
Daka	36.6^{bcde}	25.251^{de}
Dashen	32.8^{efg}	21.033^{g}
Deresel^{i}gn	26^{jklm}	20845^{g}
Enkoy	2.6^{ijkl}	11.423^{n}
ET-13A2	33.4^{cdef}	6.548o
Haw^{i}	28.2^{hijk}	17.727^{hi}
H^{i}dase	37^{bcd}	21.092^{g}
Hoggana	33.3^{def}	7.936o
Honqolo	28.9^{hij}	17.945^{h}
Kakaba	20.3^{n}o	13.101^{m}
K^{i}ngb^{i}rd	26.9^{hijkl}	16.255^{ij}
Kubsa	27.8^{hijkl}	15.093^{jk}
KBG-01	18.3o	10.062^{n}
M^{i}llen^{i}um	35.2^{cde}	14.675^{kl}
Ogolcho	39.1^{ab}	26.167^{cd}
Pavone-76	29.2^{ghij}	17.389^{hi}
Shor^{i}ma	30.2^{fghi}	13.345^{lm}
Wane	24.1^{lmn}	14.489^{klm}
Mean	30.28	19.563
SE(±)	1.31	0.537
LSD (5%)	3.82	1.563
CV	6.14	3.88
P	<0.01	<0.01

Values in a column with same letter in superscript are not significantly different at 5% probability level.

Thousand grains weight

Varieties differed significantly ($p<0.01$) for thousand grains weight which varied from 42.3 to 18.3 g with mean of all varieties 30.28 g (Table 4). Maximum grain weight (42.3 g) was found in variety, Lucy which was statistically on par with variety Ogolcho (39.1 g). The second high thousand grains weight was recorded in varieties Ga'ambo, Hidase, Daka, Millenium, Fentale-2 and ET-13 A2 (37.2 to 33.4 g). The medium thousand grains weight was found in varieties Alidoro, Hoggana, Dashen, Amibara-2, Shorima and Fentale-1 ((33.3 to 29.8 g). Low thousand grain weight was noted in varieties Pavone-76, Honqolo, Amibara-1, Hawi, Kubsa, Kingbird, Enkoy, Dereselign and Biqa (29.2g to 25g). Further, lower thousand grains weight was observed in varieties Wane, Werer-2 and Kakaba (24.1 to 20.3 g), with the lowest being in variety KBG-01 (18.3 g). As in the present investigation, significant differences among genotypes for thousand kernels or grain weights were reported by other researchers (Gebre et al., 2017; Raza et al., 2018; Amanuel et al., 2018; Bayisa et al., 2019; Mekonnen et al., 2019; Poudel et al., 2020).

Grain yield

Varieties differed significantly ($p<0.01$) for grain yield, which varied from 38.393 q/ha to 6.548 q/ha with mean of all varieties 19.563 q/ha (Table 4). Highest grain yield (38.392 q/ha) was recorded in variety, Lucy. The second highest grain yields were obtained in varieties Fentale-1, Amibara-2, Alidoro, Ogolcha, Daka, Fentale-2 and Ga'ambo (30.698 q/ha to 24.561 q/ha). The next high grain yields were found in varieties Amibara-1 and Werer-2 (22.969 to 22.792 q /ha) followed by varieties Hidase, Dashen, Dereselign and Biqa (21.092 to 19.807 q/ha). The remaining 13 varieties had lower grain yields than the mean of all varieties (19.563 q/ha). However, there were also significant differences among the low grain yielding varieties. These varieties in descending order of grain yields were as follows: Honquolo (17.945 q/ha), Hawi, Pavone-76, Kingbird, Kubsa (15.093 q/ha), Kakaba (13.101 q/ha), Enkoy, KBG-01(10.067 q/ha), Hoggana (7.936 q/ha) and ET-13A2 (6.548 q/ha). Thus, there was much genetic variation in grain yield potential of the varieties evaluated in the present investigation. As in the present studies, significant differences among genotypes/varieties for grain yield were reported by other researchers (Gebre et al., 2017; Amanuel et al., 2018; Gebreegzibher et al., 2018; Bayisa et al., 2019; Mekonnen et al., 2019). The comparison of yields of varieties indicated that varieties~~,~~ Fentale and Amibara gave 7 and 15 q/ha more yield at Arba Minch than at Were Agricultural Research Centre (WARC) but the yield of variety Werer matched with that at WARC (Bayisa et al.,2019). Increase of yield in the former varieties could be ascribed to late maturity at Arba Minch because of 3°C lower minimum temperature (18°C) at Arba Minch than at Werer (21°C). It is in line with the conclusion drawn on reviewing the effect of heat stress on wheat that for each °C increase in minimum temperature or the night temperature, the wheat yield would reduce by 6 per cent (Akter and RafiqulIslam, 2017). Variety Ga'ambo gave better yield at three low land areas in Afar district (Amanuel et al., 2018; Gebreegzibher et al., 2018) than at Arba Minch. However, the yields of varieties, Fentale, Amibara and Werer were in the same order and matched with that at Tendaho and Arba Minch, Tendaho is located in the north eastern warm Afar region (Gebreegziabhe et al., 2018), whereas Arba Minch is located in warm Southern region of Ethiopia. It is indicated that the yield varied with the genotypes and the environment. The yield could also be influenced by the genotypes by environment (G x E) interaction (Mekonnen et al., 2019, Amanuel et al., 2018; Bayisa et al., 2019; Poudel et al., 2020). The minimum and maximum temperatures, soil types and pH, relative humidity and incidence of leaf rust disease at the locations could affect the performance of varieties. However, the grain yield contributed by several characters was primarily a genotypic characteristic, but it could be influenced by environment and genotype by environment (G x E) interaction. Hence, varieties suitable for specific area adaptation and for wide adaptation could be selected by testing the performance over multiple location environments. This strategy in wheat and other crops breeding has led to selection of improved varieties with high yields adaptable to different environments. Thus, wheat varieties suitable for low land can be selected by evaluation of performance under low land areas (Gebre et al., 2017).

CONCLUSION AND RECOMMENDATION

It is concluded that the varieties Lucy, Fentale-1, Amibara-2, Alidoro, Ogolcha, Daka, Fentale-2, Ga’ambo Amibara-1 and Werer-2 were high yielding and that early maturing varieties Hidase, Dashen, Dereselign and Biqa were next in grain yield under irrigated low land at Arba Minch. Since the varieties were evaluated in one spring season from March to June 2020, it is recommended that the varieties may be further evaluated for their performance in another season and/ or main season from November to March under low land area around Arba Minch. The reaction of wheat varieties to the leaf rust disease needs to be investigated by conducting separate experiments for identifying disease resistant wheat varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Morphological studies on legume and hilum in seven species of *Vigna Savi* (Fabaceae)

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In this study of different taxa of genus *Vigna* the macro and micromorphological characters were investigated. These taxa collected from different countries (3 cultivated and 8 annual or perennial herbs) representing 7 species of this genus, namely: *Vigna radiate, Vigna trilobata, Vigna vexillata, Vigna caracalla, Vigna pubescens, Vigna unguiculata*, and *Vigna luteola*. Legume features such as shape, colour, size, surface texture, number of locules, number of legumes per peduncle seed set percentage, orientation. Moreover, by using scanning electron microscopy, additional details were obtained for stomatal shape, size, type, cuticular and wax ornamentation of the surface of the mature pod, including details of the seed such as hilum shape, size, position, ornamentation based on scanning electron microscope evidence. The usefulness of the macro and micromorphological features as criteria for taxonomic identification was emphasized.

Key words: *Vigna*, Fabaceae, morphological characters, pod, hilum, S.E.M., taxonomy.

INTRODUCTION

Fabaceae Lindley is the largest of the third largest family of flowering plants, with ca. 19,500 species in 770 genera (Polhill and Raven, 1981; Christenhusz and Byng, 2016; LPWG, 2017). The genus *Vigna* Savi belongs to the tribe *Phaseoleae* DC., subtribe *Phaseolinae* Benth. (sub family Faboideae, family Fabaceae) widely cultivated with ca. 200 species distributed in tropical and sub-tropical regions (Fery, 2002; Gaafar, 2007; El-Ghamery et al., 2012). Previous studies of this genus based on morphological characters were made by Verdcourt (1970), Maréchal et al. (1978, 1981), Ng and Maréchal (1985), Pasquet (1993), Tomooka et al. (2002, 2003), Ng (1990), and GRIN (2005). The genus is divided into 7 subgenera: *Ceratotropis* (Piper) Verdcourt, *Haydonia* (R. Wilczek) Verdcourt, *Plectrotropis* (Schumach.) Baker., *Sigmidotropis* (Piper) Verdcourt, *Lasiosporon* (Piper) Benth., *Macrodonta* Verdcourt and *Vigna* with 16 sections and containing 81 species.

Economically *Vigna* is a source of plant protein for human food and animal feed in tropical, sub-tropical, arid and semi-arid regions, and also plays an important role in soil fertility by fixing nitrogen (Mbagwu and Endeoga, 2006; Pule-Meulenberg et al., 2010; Sprent et al., 2010; El-Ghamery et al., 2012; El-Gazzar et al., 2013; Popoola et al., 2015). Barthlott and Ehler (1977) maintained that the epidermal features are variable for angiosperm taxa and can be used to evaluate possible relationships. Seed morphological characters are useful in the analysis of of taxonomic distinguish inter and intra relationships in a wide variety of plant families (Esau, 1953; Shetler and Morin, 1986; Takhtajan, 1991; Buss et al., 2001; Zhang et al., 2005; Gontcharova et al., 2009). In addition to

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Table 1. Species, accessions number, origen, subgenera and sections of the studied taxa of Vigna Savi.

S/N	Species	Acce. No.	Origen	Subgenus	Section	Habit
1	*V. radiata* (L.) R. Wilczek	6789	Ethiopia	*Ceratotropis*	*Ceratotropis*	A.herb
2	*V. radiata* (L.) R. Wilczek	-	Egypt	*Ceratotropis*	*Ceratotropis*	A.herb
3	*V. trilobata* (L.) Verdc	114	Sudan	*Ceratotropis*	*Ceratotropis*	A.herb
4	*V. vexillata* A. Richard	51	Ethiopia	*Plectotropis*	*Plectotropis*	P. herb
5	*V. caracalla* (L.) Verdc.	11057	Ethiopia	*Sigmoidotropis*	*Caracallae*	P. herb
6	*V. pubescens* Wilczek	43	Ethiopia	*Vigna*	*Catiang*	P. herb
7	*V. pubescens* Wilczek	-	Saudi Arabia	*Vigna*	*Catiang*	A. herb
8	*V. unguiculata* (L.) Walp.	9333	Ethiopia	*Vigna*	*Catiang*	A. herb
9	*V. unguiculata* (L.) Walp.	-	Egypt	*Vigna*	*Catiang*	A. herb
10	*V. unguiculata* (L.) Walp.	-	Egypt	*Vigna*	*Catiang*	A. herb
11	*V. luteola* Benth.	34	Ethiopia	*Vigna*	*Vigna*	A. herb

A= Annual, P= Perennial.

general characters of morphology of seeds, sculpturing details of outer seed coat are quite variable between different species and can be of a systematic importance (Chowdhury and Buth, 1970; Gohary and Mohammed, 2007). The importance of ultrastructural pattern analysis of the seed coat observed under the SEM has been well recognized as a reliable approach for assessing phenetic relationship and identification of species or taxa (Barthlott, 1981; Tobe et al., 1987; Koul et al., 2000; Yoshizaki, 2003; Javadi and Yamaguchi, 2004).

The micro-morphological characters of the seed and legume surface can be useful for delimiting taxa at various levels (Karcz et al., 2005; Akçin, 2008; Khafagi et al., 2018). Legume colour that is less affected by environmental variations has been used as a marker for the identification of species or varieties (Sangwan and Lodhi, 1998). In *Vigna* species, many taxonomists have used seed and hilum morphology and micromorphology to differentiate the species (Chandel et al., 1991; Nath and Dasgupta, 2015; Umdale et al., 2017). This work aims to describe the significance of macro and micromorphological characters of legume and hilum using SEM in 11 taxa of the genus *Vigna* and its implication in the classification of this plant.

MATERIALS AND METHODS

Seeds of *Vigna* Savi accessions were obtained from the International Livestock Center for Africa (ILCA), Jazan Region of Saudia Arabia and from different localities in Egypt. Eleven taxa representing 11 species belonging to genus *Vigna* Savi were investigated. The sources and origins of these taxa are given in Table 1. Seeds were germinated in April 2019, at the Botanic Gardens of the Botany Department, Faculty of Science, New valley University, Egypt. Flowering began in June 2019. Samples of complete mature plants were collected, including fruits and seeds. Authentic specimens of all taxa were pressed, dried and deposited as herbarium specimens at the Botany Department, Faculty of Science, New Valley University. The morphological characters were examined, which included legume shape, colour, size, texture, apex, shattering, seed per pod, locule per pod, seed set percentages, pod attachment, number of pods per peduncle, and stomata on the surface of a mature pod. Hilum shape, size, colour and position features of different species were also noted. The seed set percentage was calculated using the formula described by Popoola et al. (2015) as follows:

$$\text{Seed set \%} = \frac{\text{No. of seed / pod}}{\text{No. of locule / pod}} \times 100$$

For preparation of legume and seeds of each taxon to scan the surface by using the scanning electron microscope (SEM), legumes and seeds from each taxon were divided into two groups. The first group was mounted on an adhesive surface and prepared for SEM investigation. The second group was washed thoroughly using distilled water to remove any impurities on the seed surfaces; then they were dried and soaked in 10% HCl for 6 h to remove the coat enveloping the seed (Ismail and El-Ghazaly, 1990). This was followed by washing the seeds with distilled water and then dried and prepared for SEM examination by mounting these dry legumes and seeds onto clean stubs using double-sided adhesive tape. These clean dry legumes and seeds were gold coated using a JEOL JFC 1100E ion-sputtering device. Then, the coated seeds were viewed and photographed with a JOEL ISM-5500LV scanning electron microscope, operated at accelerating voltage of 15 KV at the Scanning Electron Microscopy Unit in the Regional Center for Mycology and Biotechnology, Al-Azhar University. Magnifications of images were denoted with scale bars either in mm or µm as appropriate. Measurements (L x B) of legumes and seeds were taken using a measuring scale. Seeds were uniformly scanned at the hilum, the surface surrounding both sides of the hilum, and the surface pattern was highlighted to observe the cellular and intercellular patterns. The terminology for describing seed coat patterns follows Barthlott (1981, 1990) and Stearn (1996). Details of the species used are presented in Table 1.

RESULTS

Legume

The legume morphological characters of the studied taxa are given in Table 2, represented in Plate 1 (1a, 2a, 3a,

Table 2. Pod morphometric characteristic of the studied taxa.

N	Species	Shape	Colour	Size		Exocarp hairiness	Pod apex	Pod shattering	Seed / Pod	Locules / Pod	Seed set %	Pod orientation	No. Pod / Peduncle
				Length (cm)	Width (cm)								
1	*V. radiata*	Linear - terete	Black	4-5	1.4-1.6	Pubescent	Straight beak	Present	5-6	6-8	75-83	Erect	4-6
2	*V. radiata*	Linear - terete	Brown	6-8	1.4-1.5	Scabrous	Straight beak	Absent	8-10	9-12	83-89	Pendent	5-8
3	*V. trilobata*	Linear - terete	Black	2.5-3	0.8-0.9	Glabrous	Straight beak	Present	5-6	6-8	75-83	Erect	6-8
4	*V. vexillata*	Linear - terete	Brownish black	11-12	1-1.1	Puberulous	Declined beak	Present	10-12	11-14	86-91	Erect	4-6
5	*V. caracalla*	Linear - flat	Gray	7-8	1.9-2	Glabrous	hooked	Absent	8-10	9-13	76-89	Pendent	5-7
6	*V. pubescens*	Linear - terete	Black	7-8	0.9-1	Pubescent	Declined beak	Present	7-9	8-11	82-88	Erect	4-6
7	*V. pubescens*	Linear - terete	Creamy	6-7	1- 1.1	Pubescent	Declined beak	Present	6-7	8-10	70-75	Pendent	4-6
8	*V. unguiculata*	Curved - terete	Creamy	17-23	2.4-2.6	Glabrous	Declined beak	Absent	20-25	22-28	89-91	Pendent	4-6
9	*V. unguiculata*	Curved - terete	Creamy	12-15	1.5-1.8	Glabrous	Declined beak	Absent	7-12	9-15	83-87	Pendent	4-6
10	*V. unguiculata*	Curved - terete	Creamy	16-17	2.2- 2.5	Glabrous	Declined beak	Absent	15-18	16-20	93-94	Pendent	5-7
11	*V. luteola*	Linear - terete	Brown	4-5	1.3-1.5	Glabrous	Declined beak	Present	7-8	9- 11	73-78	Erect	8-9

4a and 5a) and Plate 2 (6a, 7a, 8a, 9a, 10a and 11a).

Legume shattering, shape and apex

The results in Table 2 show all studied *Vigna* species have a shattering (dehiscent) legume, except *Vigna unguiculata*, *Vigna caracalla* and *Vigna radiata* (No.2) collected from Egypt. The time of legume shattering is related to the maturity of the legumes; also all studies species were of the linear-terte legume shape, except *V*. *unguiculata* that is slightly curved and *V*. *caracalla* that is linearly flat. The apex of legume is straight beak in the subgenus *Ceratotropis*. There is declined beak in the subgenus Plectrotropis and subgenus Vigna and a hooked beak in the subgenus Sigmidotropis (Table 2, Plate 1 (1a, 2a, 3a, 4a, 5a) and Plate 2 (6a, 7a, 8a, 9a, 10a and 11a).

Colour

Legume colour at maturity varied from black, brown, brownish black, gray to creamy. It was black in *V*. *radiata*, *Vigna trilobata* and *Vigna pubescens* collected from Ethiopia, while brown in *V*. *radiata* collected from Egypt and *Vigna luteola* collected from Ethiopia, brownish black in *Vigna vexillata*, gray in *V*. *caracalla* and creamy in *Vigna pubescens* collected from Saudi Arabia and *V*. *unguiculata* (Table 2 and Plate 1 (1a, 2a, 3a, 4a, 5a) and Plate 2 (6a, 7a, 8a, 9a, 10a and 11a).

Surface texture

Surface texture of *V*. *pubescens* and the cultivated of *V*. *radiata* was pubescent, while in the *V. radiata* wild scabrous, glabrous in *V*. *trilobata* and *V*. *caracalla*, *V*. *unguiculata* and *V*. *luteola* (Table 2, Plate 1 (1a, 2a, 3a, 4a, 5a) and Plate 2 (6a, 7a, 8a, 9a, 10a and 11a).

Size

Three categories of legume size are recognized the smallest are those of wild species *V*. *trilobata*,: *V*. *radiata* and *V*. *luteola*; while the legume of *V*. *radiata* cultivated, *V*. *pubescens* and *V*. *caracalla* are of medium size. The remaining species have long legume (Table 2, Plate 1 (1a, 2a, 3a, 4a, 5a) and Plate 2 (6a, 7a, 8a, 9a, 10a and 11a).

Number of seeds per legume

The number of seed per legume was recognized into two categories: the first with less than 10 seeds (*V*. *radiate*, *V*. *trilobata*, *V*. *caracalla*, *V*. *pubescens* and *V*. *luteola*) and the second with more than 10 seeds (Table 2).

Number of locules per legume

The number of locules per legume 6-8 in *V*. *radiata* and *V*. *trilobata*, 9-11, 9-12, 9-13 in *V*. *luteola*, *V*. *radiata* were collected from Egypt and *V*. *caracalla* respectively, while 8-10, 8-11 in *V*. *pubescens*, 22-28, 9-15, 16-20 in *V*. *unguiculata* respectively (Table 2).

Table 3. Exocarp features (stomata characters and Cuticular ornamentation) of the pod in the studied taxa.

Character / Taxa	Level	Shape	Size		Rim	Peristomatal rim	Cuticular ornamentation
			L (µm)	W (µm)			
V. radiata	Semidepresed	Elliptical	18-19	8-10	Raised	Present	Favularite
V. radiata	Semidepresed	Elliptical	15-18	7- 9	Raised	Present	Favularite
V. trilobata	Semidepresed	Elliptical	21-23	9-12	Raised	Present	Favularite
V. vexillata	Superficial	Broad-Elliptical	30-33	17-20	Raised	Present	Ruminate
V. caracalla	Semidepresed	Narrow-Elliptical	16-18	4-6	Raised	Present	Rugose
*V. pubescen*s	At level	Elliptical	18-20	8-10	Raised	Present	Rugose
*V. pubescen*s	At level	Elliptical	18-20	8-10	Raised	Present	Reticulate
V. unguiculata	At level	Elliptical	23-26	10-14	Raised	Present	Reticulate
V. unguiculata	At level	Elliptical	20-23	8-12	Raised	Present	Reticulate
V. unguiculata	At level	Elliptical	20-24	8-12	Raised	Present	Reticulate
V. luteola	At level	Elliptical	10-14	5-7	Raised	Present	Reticulate

Orientation

Two types of pod orientation were observed as erect and pendent. In *V. radiata*, collected from Egypt, and in *V. unguiculata* and *V*. *caracalla* the legume is pendent; while the legume is erect in *V*. *radiata*, *V*. *trilobata*, *V*. *vexillata* and *V*. *luteola*.

Seed set percentage

Seed set percentage was reported as two categories: the first less than 75% in wild *V*. *pubescens* while the second more than 75% in the remainder of the studied species (Table 2).

Stomata on the surface of mature legume

Most of the studied taxa possess barely sunken elliptical stomata with raised stomatal rims and long narrow aperture; the stomatal leveling ranged between superficial, at a level and semi-depressed. It is superficial only in *V*. *vexillata*, semidepresed in *V*. *radiata V*. *trilobata* and *V*. *caracalla* and at the level in the remainder of the studied taxa.

The shape

Shape of stomata is broadly to narrowly elliptical in *V*. *vexillata* and *V*. *caracalla* (Table 3; Plate 1, (4b and 5b); while elliptical shaped in the remainder of the studied taxa (Table 3; Plate 1 (1b, 2b, 3b) and Plate 2 (6b, 7b, 8b, 9b, 10b and 11b).

The size

There is an inter and intra-specific variation in the stomatal size. Stomata ranged in size from 10-33 × 4-20 µm (length × width). However, the largest stomata are those of *V*. *vexillata* 30-33 µm long, and 17-20 µm wide. The smallest are those of *V*. *luteola* 10-14 µm long, 5-7 µm wide (Table 3).

The rim

Rims are usually broad and raised in all taxa. Most of the studied taxa possess stomata with one stomatal rim and peristomatal rim.

Cuticular and wax ornamentation

The reticulate cuticular ornamentation was recorded for *V*. *luteola*, section *Vigna* and *V*. *unguiculata*, *V*. *pubescence* collected from Saudia Arabia section Catiang while it is rugose in *V*. *pubescen*s collected from Ethiopia. It is favularite in *V*. *radiata* and *V*. *trilobata* section Ceratotropis, while rugose in *V*. *caracalla* section Segmidotrops and ruminate in *V*. *vexillata* section Plectrotrops (Plate 1 (1b, 2b, 3b, 4b, 5b) and Plate 2 (6b, 7b, 8b, 9b, 10b and 11b; and Table 3).

Hilum

Position

The hilum in the examined seeds was located in central position as shown in *V. radiata*, *V. trilobata* and *V. caracalla* Plates 3 (Figures 1, 2, 3, 4 and 5); whereas, the hilum was subcentral in the remainder of the studied taxa (Table 4; Figures 6, 7, 8, 9, 10 and 11 (Plates 4)). The hilum shape was oblong in *V*. *radiata*, elliptical in *V*. *vexillata*, *V*. *caracalla* and *V*. *luteola*, ovate in the other taxa; and the level is sunken in *V*. *caracalla* while raised in the remaining taxa.

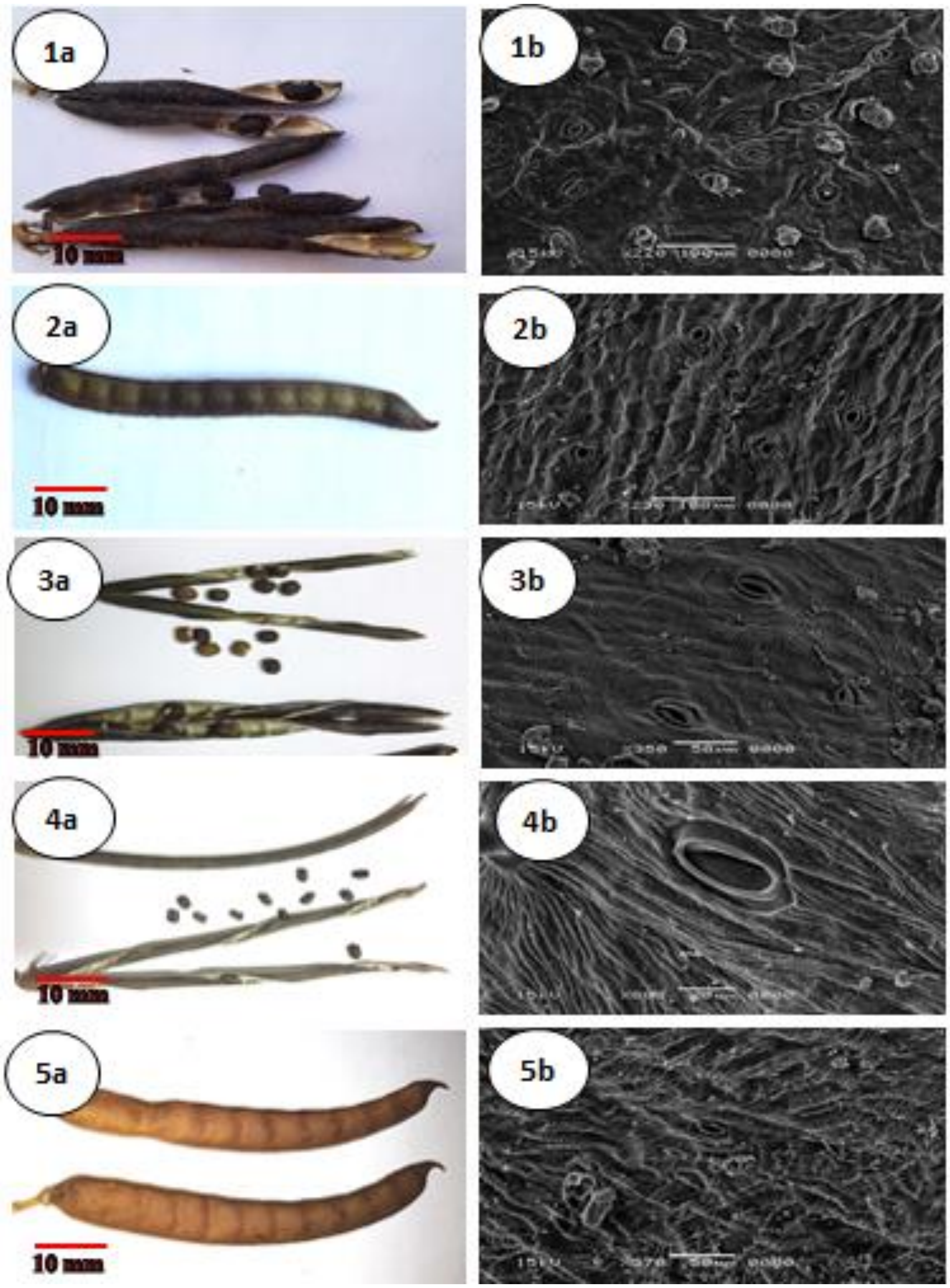


Plate 1. Photograph and S.E.M micrographs of pod. (1a, b) *V. radiata* wild; (2 a, b) *V. radiata*; (3a, b) *V. trilobata*; (4a, b) *V. vexillata*; (5a, b) *V. caracalla.*

The size

The size of hilum varied in all studied species and their accessions, where the size ranged from 2.0-3.0 mm ×1.0-1.4 mm to 0.7-1.0 × 0.5-0.7 mm (Length × Width). The longest size (2.0-3.0 mm) was found in *V. unguiculata* from Egypt (No. 8), (Figure 8), followed by 1.8 -2.0 mm in *V. unguiculata* from Ethiopia (No. 10), (Figure 10); the lowest one was found in *V. trilobata*, 0.7 - 1.0 mm long, 0.5 - 0.7 mm wide (Figure 3).

The data in Table 4 show that there is a high difference in the size of the hilum between the taxa of the same species of the studied genus as in *V. unguiculata* (2.0-3.0 mm length, 1.6-1.7 mm length and 1.8-2 mm length), *V. radiata* (1.4-1.6 mm length and 1.2-1.4 mm length) and *V. pubescens* (1.1-1.3 mm length and 1.3-1.5 mm length); *V. luteola* (1.3-1.5 mm length) *V. vexillata* (1.2-1.6 mm length), and *V. caracalla* (1.4-1.6 mm length).

Table 4. Hilum characters and cuticular ornamentation of the studied taxa.

Species	shape	level	Position	Size		Rim aril	Rim colour	ornamentation
				Length (mm)	Width (mm)			
V. radiata	Oblong	Raised	Central	1.4-1.6	0.5-0.6	Absent	Yellowish brown	Rugose
V. radiata	Oblong	Raised	Central	1.2-1.4	0.4-0.5	Absent	Black	Reticulate
V. trilobata	Ovate	Raised	Central	0.7-1.0	0.5-0.7	Absent	Brown	Reticulate
V. vexillata	Elliptical	Raised	Sub central	1.2-1.6	0.5-0.7	Present with superficial expansion and cleft margin	Black	Regulate
V. caracalla	Elliptical	sunken	Central	1.4-1.6	0.6-0.7	Present with superficial expansion and cleft margin	Black	Compact
V. pubescens	Ovate	Raised	Sub Central	1.1-1.3	0.4-0.5	Present with superficial expansion	Brown	Reticulate colliculate
V. pubescens	Ovate	Raised	Sub Central	1.3-1.5	0.6.-0.7	Present with superficial expansion	Brown	Reticulate colliculate
V. unguiculata	Ovate	Raised	Sub Central	2.0-3.0	1.0-1.4	Present with superficial expansion	Black	Regulate
V. unguiculata	Ovate	Raised	Sub Central	1.5-1.7	0.6-0.7	Present with superficial expansion	Brown	Regulate
V. unguiculata	Ovate	Raised	Sub Central	1.8-2.0	0.7-0.8	Present with superficial expansion	Brown	Regulate
V. luteola	Elliptical	Raised	Sub Central	1.3-1.5	0.5-0.6	Present with superficial expansion	Brown	Reticulate foveate

The rim aril and colours

The term aril is used for a fleshy to hard structure that develops from the funiculus or ovule after fertilization and invests part or all of a seed. Rim aril was absent in *V. radiate* and *V. trilobata*; whereas, it is well developed with superficial expansion and a cleft margin in *V. vexillata* and *V. caracalla*. However, in the remainder of the taxa, the aril is well developed with superficial expansion without cleft margin. Diverse rim colours were observed varying from black, brown to yellowish brown (Figures 1a, 2a, 3a, 4a, 5a, 6a, 7a, 8a, 9a, 10a and 11a and Table 4).

Ornamentation

The examinations of hilum surface by S.E.M showed different types of ornamentations were present in cultivated *V. radiate*. Among the ornamentation, there was rugose structure type, wax flakes depositions; and heavy globular waxy depositions of various size were also clearly seen. The hilum in wild *V. radiata* and *V. trilobata* was reticulate with some waxy flakes. In *V. vexillata* it is rugulose striate, while in *V. caracalla*, the cells of hilum are disposed in a uniserate compact filament and are fusiformed with the rim. However, in *V. pubescens* the hilum is reticulate colliculate. In *V. unguiculata* there is regulate pattern, and it contains a furrow-like array of longitudinal cells with light waxy deposition. The hilum of *V. luteola* is reticulate foveat (Figures 1b, 2b, 3b, 4b, 5b, 6b, 7b, 8b, 9b, 10b and 11b; Table 4).

DISCUSSION

In this study, our observations of the macro and micromorphological features revealed the presence of considerable morphological variations between the different subgenus species. In subgenus C*eratotropis,* the pods are pendent, non-shattered and brown in colour in cultivated *V. radiate*. Whereas, it is erect, shattered and black in colour in wild *V. radiata* and *V. trilobata* at maturity. In subgenu *Plectrotropis*, the pod is erect, shattered and brownish black in colour. In subgenus *Sigmoidotropis,* the pod is pendent and non-shattered; and grey in colour. In the subgenus *Vigna*, the pod is pendent and shattered or non-shattered/erect and shattered. In this respect these variations were previously observed by many authors such as Garba and pasqet (1998), Sangwan and Lodhi (1998), Peksen and Peksen (2013), and Popoola et al. (2015, 2017). Many accessions within *V. unguiculata* show long and relatively large seeds with seed coat colour or patterns similar to the cultivated cowpea; although, some of their character's pod structure, pod position on the raceme and pod shattering are characteristics of the wild species. Also, diversity of *V. vexillata* is also well represented on the variability of the surface pubescence (that is, plant almost glabrescent, densely pubescent to bristly) as reported by Padulosi and Ng (1993).

The number of seeds per pod of the cultivated *V. unguiculata* (7-12 seeds) was relatively small compared with the cultivated (No. 8), (20-25 seeds) followed by the wild form of this species

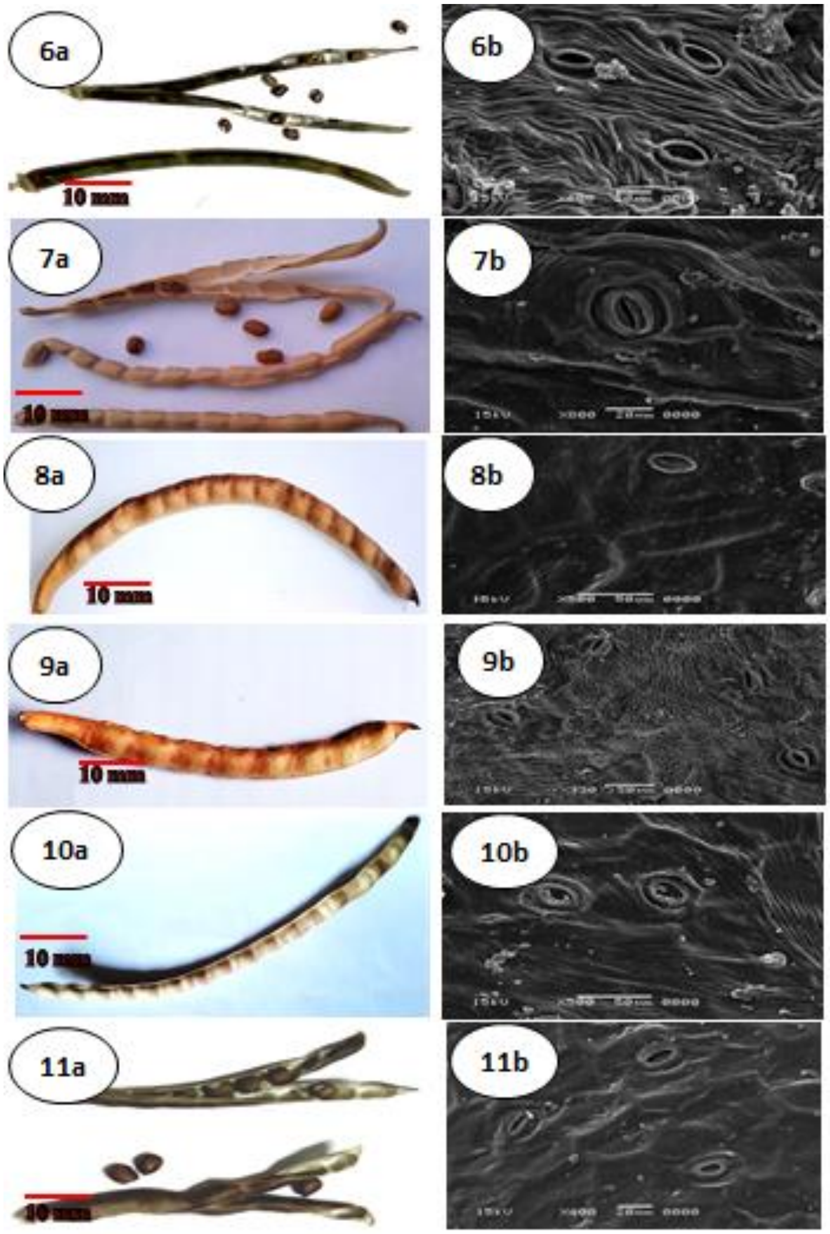


Plate 2. Photograph and S.E.M micrographs of pod. (6a, b) *V. pubescens* Ethiopia; (7a, b) *V. pubescens*; (8a, b) *V. unguiculata*; (9a, b*) V. unguiculata*; (10a, b) *V. unguiculata*, wild, (11a, b) *V. luteola*.

(15-18 seeds) from subgenus *Vigna*; and the other studied species which had a range of 6-10 seeds. However, the seeds per pod of the two accessions of *V. radiata* and *trilobata* (5-6 seeds) from subgenus *Ceratotropis* were relatively small compared with the other studied species of *Vigna*. A similar variation in the pod size for different taxa of *Vigna* was reported by many investigators, and it could be attributed to the geographical distribution of these taxa (Barrett, 1990; Hymowitz, 1990; Pasquet, 1998; Pasquet and Vanderborght, 2000; Fery, 2002; Bisht et al., 2005). The usage of the scanning electron microscope (SEM) studies in examination of legume surface of 7 species of *Vigna* (11 accessions) revealed the importance of this technique as a taxonomic tool. The results in this investigation showed fairly heterogeneous stomatal surface patterns of the legume in the different species of *Vigna*; and also this data offer significant information to be used in classification similar to that studied by El-Hadidy (2004) for the genus *Lotus*, family Fabaceae.

The seed of *V*. *radiata* and *V*. *trilobata* section Ceratotropis has no rim-aril, while the other species

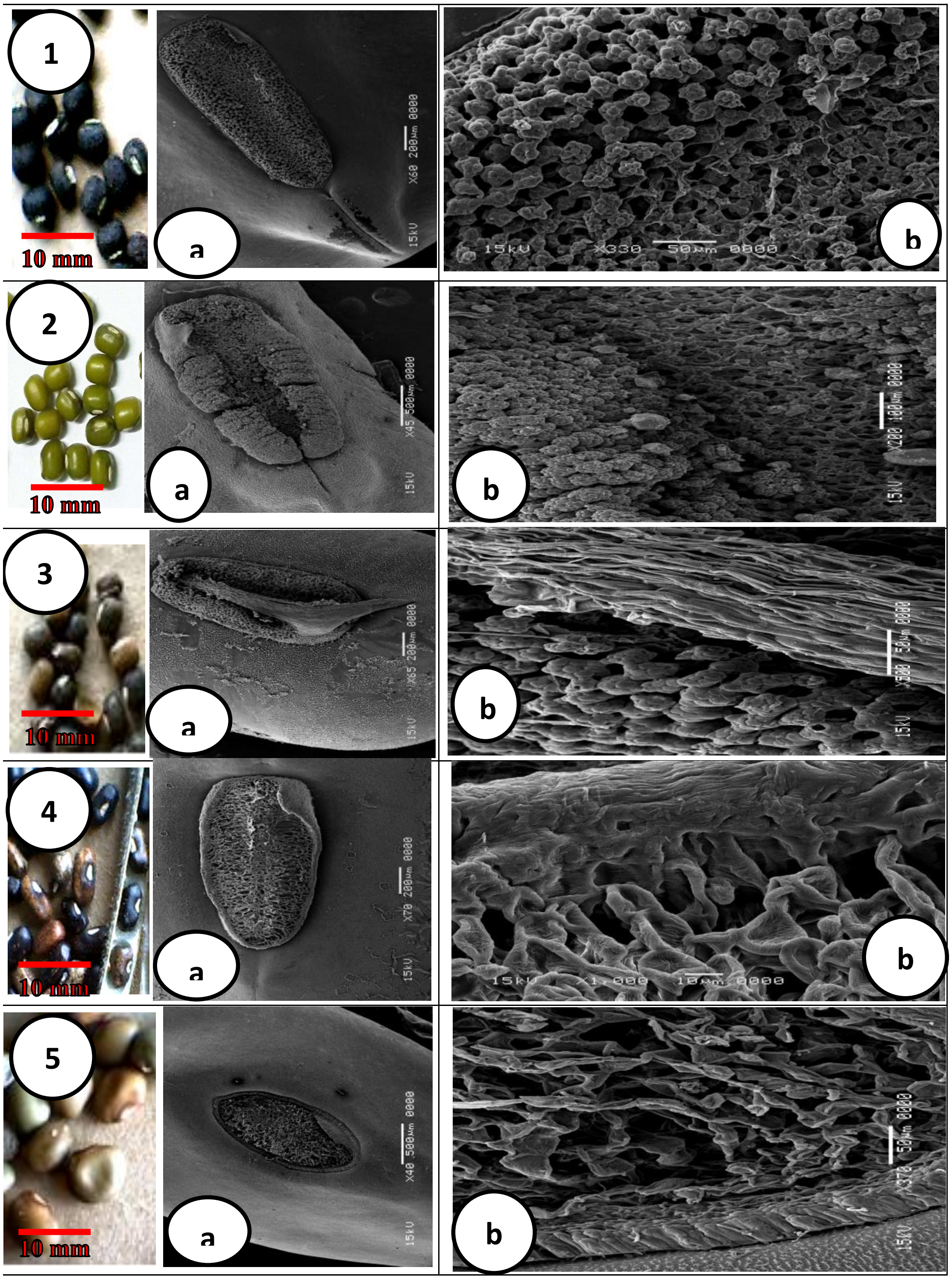
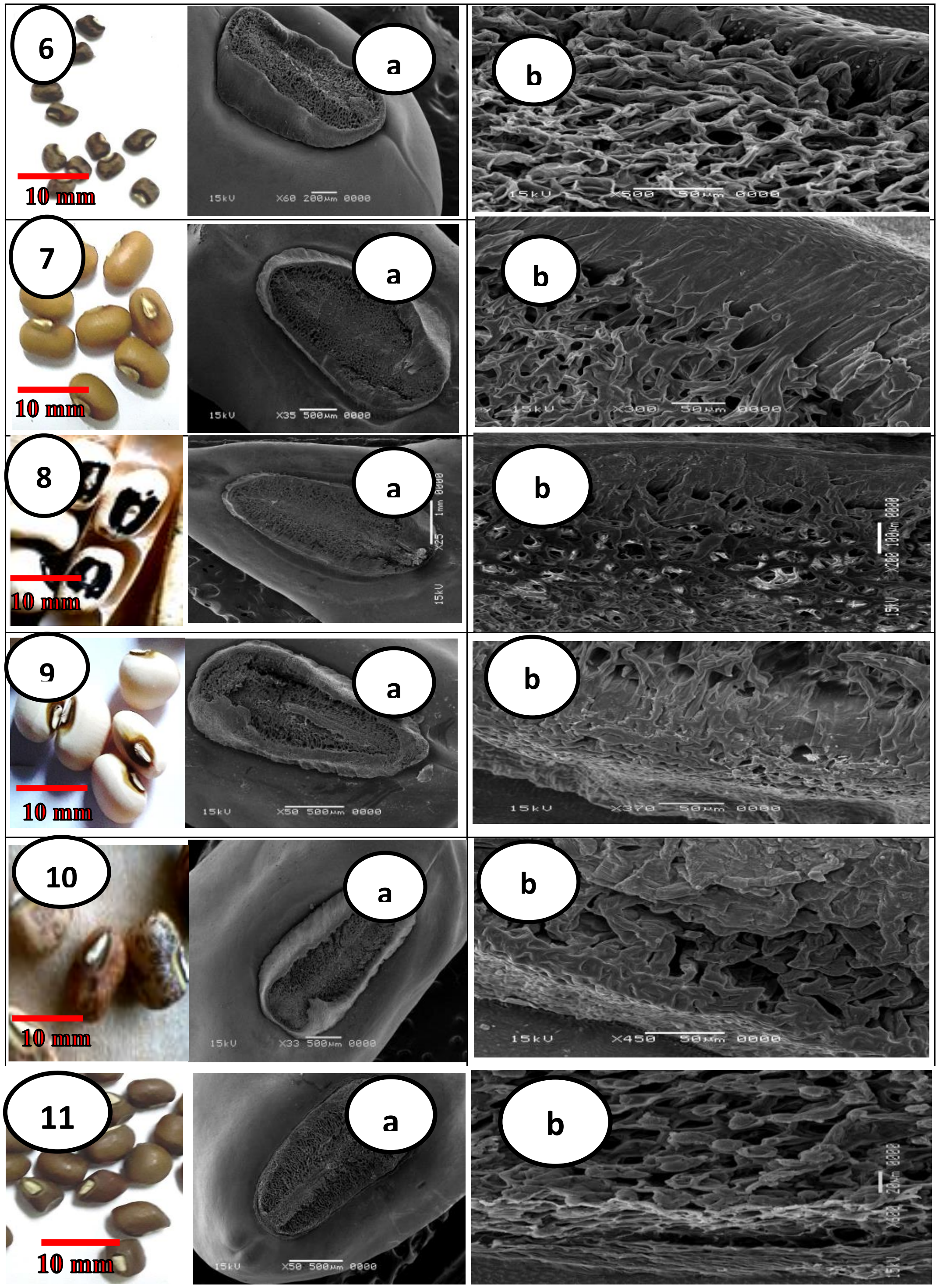


Plate 3. (Figures 1-5). Photograph of seed and S.E.M micrographs of Hilum. **(1–a, b)** *V. radiata* wild; **(2–a, b)** *V. radiata* cultivated; **(3–a, b)** *V. trilobata*; **(4–a, b)** *V. vexillata*; **(5–a, b)** *V. caracalla*.

studied have a superficial expansion of the rim aril. In comparison, *V*. *vexillata* section Plectrotropis and *V*. *caracalla* section Sigmidotropis have a superficial expansion with cleft margin, which is comparable to the dry tongue aril illustrated by Gunn (1981) for some Papilionoideae taxa. These observations are also in



Plates 4. (Figure. 6-11). Photograph of seed and S.E.M micrographs of Hilum. **(6–a, b)** *V. pubescens* Ethiopia; **(7–a, b)** *V. pubescens*; **(8–a, b)** *V. unguiculata*; **(9–a, b)** *V. unguiculata*; **(10–a, b)** *V. unguiculata*, wild, **(11–a, b)** *V. luteola*.

agreement with the studies of Fabiana et al. (2013) and Khedia et al. (2017), on some species of *Vigna*.

The examination of hilum ornamentation of some species, that were studied here for the first time by SEM, have demonstrated the existence of diversity in various taxa; and revealed that the mature seed surface pattern is not identical; rather it showed the presence of a remarkable difference between the two collected accessions of each species such as in wild and cultivated forms collected from different countries. In contrast, the spermoderms of both collected taxa of *V*. *pubescens* are reticulate colliculate, regulate in *V*. *vexillata* and *V*. *unguiculata*, compact in *V*. *caracalla*, rugae in *V*. *radiata* wild while reticulate in *V*. *radiata* cultivated, and reticulate foveate in *V*. *luteola*; as also was illustrated by Kumar and Rangaswamy (1984), Fabiana et al. (2013) and Khedia et al. (2017).

Conclusion

The macro and micro-morphological characteristics of legume and hilum were reported. This includes legume features such as shape, colour, size, surface texture, number of locules, number of legumes per peduncle, seed set percentage, and orientation. Moreover, by using scanning electron microscopy, additional detailed information was obtained such as stomatal shape, size, type, cuticular and wax ornamentation of the mature pod surface. In addition, hilum shape, size, position, and ornamentation were elucidated by using scanning electron microscopy. The results provide clear and important attributes of these species for the definition and identification of the taxa collected from different countries.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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