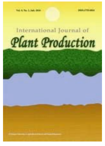

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Hay yield and quality of oat (*Avena sativa* L.) genotypes of worldwide origin

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Abstract

Oat (*Avena sativa* L.) traditionally has been a major crop for feed and forage in Turkey. The objective of this research was to study hay yield and quality of oat genotypes harvested at the late milk stage. One hundred oat varieties of worldwide origin were compared in field experiments in Samsun (northern Turkey) over two growing seasons (2007-2008 and 2008-2009). Significant differences between the tested oat varieties were observed for the plant height, hay yield, crude protein (CP), acid detergent fibre (ADF), neutral detergent fibre (NDF), total digestible nutrients (TDN), relative feed value (RFV) and macro minerals (Ca, K, P and Mg). Plant height varied from 76.2 to 141.2 cm, hay yield from 6.03 to 11.83 t ha^{-1}, crude protein from 58.8 to 136.4 g kg^{-1} dry matter (DM), acid detergent fibre from 333.2 to 424.8 g kg^{-1} DM and neutral detergent fibre from 522.5 to 652.4 g kg^{-1} DM. The TDN ranged from 465.1 to 583.3 g kg^{-1} and relative feed value from 80.9 to 112%. Cluster analysis grouped the 100 genotypes within 7 clusters, each of which having 17, 21, 13, 12, 20, 12 and 5 genotypes. Sisko, Akiyutaka, Longchamp, Sanova, Flämingslord, Matra and Revisor were identified as the high hay yield potential genotypes. However, quality traits of these genotypes were lower than some of other genotypes. Furthermore, while some macro minerals were insufficient, others were in excess regarding healthy feeding. Hence, some form of commercial mineral supplement would be required to oat-based ration or oat should be grown in mixtures with legumes for feeding productive livestock.

Keywords: Oat genotypes; Hay yield; Hay quality; Mineral content.

Introduction

In Turkey, quality forage is needed for present livestock because the productivity of Turkey's rangeland is very low and other forage production sources are extremely insufficient. As alternative feed source, uses of small grain cereals forage could be partly solved for scarcity of available forage (Çelik and Bulur, 1996). Cereals (wheat, barley, oat, rye and triticale) are important forage for livestock feeding. Traditionally, summer grazing and cereal straw feeding in winter are the major sources of ruminants in Turkey (Büyükburç, 1993). Oats are grown for both grain and forage for livestock feeding over a long time in many parts of the world (Stevens et al., 2004). In Turkey, oats are grown as both a sole crop and intercropped with annual forage legume plant species for forage. Oat forage yield and quality are determined by numerous variable factors such as genotype, environment and management practices (Kim et al., 2006). Grain oat cultivars/ genotypes were used as forage in some investigation (Chapko et al., 1991). Chapko et al. (1991) indicated that distinctive breeding program for forage quality cannot be continued and then grain oat genotypes may satisfy forage needs. Most of the previous studies were showed that late-maturing genotypes had higher forage yield than early-maturing genotypes (Riveland et al., 1977; Chapko et al., 1991; Aydın et al., 2010). Chapko et al. (1991), Aydın et al. (2010) indicated a positive association between forage and plant height, while Riveland et al. (1977) notified that both tall and short genotypes produced high forage yields. Also, some researcher indicated that no relationship between forage yield and grain yield (Stuthman and Marten, 1972; Folkins and Kaufmann, 1974; Chapko et al., 1991). Stuthman and Marten (1972), Chapko et al. (1991) and Aydın et al. (2010), however, reported a negative association between forage yield and quality. Stage of maturity at harvest for forage has the greatest effect on forage yield and quality of cereals (Cherney and Marten, 1982; Bergen et al., 1991; Juskiw et al., 2000). Bergen et al. (1991) reported that the optimal stage of harvest for barley and oat to maximize forage yield and quality traits is the soft-dough stage. Although oat forage yield nearly doubles from the boot to hard dough stage, ADF and NDF values with maturity increase and forage quality rapidly declines (Mut et al., 2006). Quality forage must have high intake, digestibility and efficiency of utilization (Juskiw et al., 2000). ADF (acid detergent fiber) and NDF (neutral detergent fiber) are good indicators of fiber contents in forages. Acid detergent fiber (ADF), a measure of the digestible fraction, is an important measure of forage quality. But, the neutral detergent fiber (NDF) or cell wall content is associated with dry matter intake of the forage. Protein content is also an essential factor for determining feeding value of forage. Cereal forages are versatile, economic sources of digestible fiber, protein and minerals. Forage and animal scientists are also aware of the importance of the concentrations of Ca, Mg, K, Cu and Zn and the K/(Ca + Mg) ratio in diets for ruminants (Kidambi et al., 1989).

There is a need for continued effort for recent data (agronomic adaptation, hay yield and quality) as new crop genotypes become available for forage cropping systems of the region. Therefore, this research was conducted to investigate hay yield and quality among different oat genotypes.

Materials and Methods

This study was carried out in experimental field at the Department of Field Crops, Faculty of Agriculture, Ondokuz Mayis University (41° 21′ N, 36° 15′ E and 195 m a.s.l.) during the 2007-2009 growing seasons. Some climatic data and soil characteristics of the experimental area are given in Tables 1 and 2. One-hundred grain oat genotypes obtained from Europe, North and South America, Asia and Oceania were used as plant material in this study. The genotypes were tested in incomplete block design (10×10 alpha lattice) with three replications. Names and origin of the genotypes are given in Table 3. Each genotype was sown in 4.8 m^2 (1.2 by 4.0 m) plots consisting of six rows with 20 cm row spacing at the beginning of November in 2007 and 2008. Plots were fertilized with 60 kg ha^{-1} N and 60 kg ha^{-1} P at sowing. Maturity at harvest was determined using Zadoks scale (Zadoks et al., 1974). Harvest was done at late milk stage (Zadoks scale 77).

A sub-sample (800 to 1000 g) was randomly selected from each harvested plot to estimate hay yield and provide samples for forage quality analysis. The samples were weighed and dried for 72 h by forced-air drying oven at 65 °C. The dried samples were reassembled and ground to pass through a 1 mm screen. Crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF) and Ca, K, Mg and P contents of samples were determined using near infrared reflectance spectroscopy (NIRS) (Poblaciones et al., 2008). Software options CENTER and SELECT (Win ISI II v.1.5, Foss NIR Systems, Silver Springs, MD, USA) were used for calibration equation development.

Total digestible nutrients (TDN), dry matter intake (DMI), digestible dry matter (DDM) and relative feed value (RFV) were estimated according to the following equations (Lithourgidis et al., 2006).

TDN = (-1.291 X ADF) +101.35,

DMI = 120 / %NDF dry matter basis,

DDM = 88.9 – (0.779 X %ADF dry matter basis),

RFV = %DDM X % DMI X 0.775

All data for two years (2007-08 and 2008-09) were combined because of homoscedasticity. All data was adjusted by correction factor and analyzed with analysis of variance (ANOVA) procedures using the MSTAT-C statistical software. The mean comparison among genotypes was obtained by using the least significant difference (LSD) test (Steel and Torrie, 1980). The cluster analysis was performed according to Ward for grouping populations (Johnson, 1998). Data was statistically analyzed by SAS software.

Table 1. Some climatic values of the study area.

	Total monthly rainfall (mm)			Mean monthly Relative humidity (%)			Mean monthly temperature (°C)		
	2007-08	2008-09	30-year average	2007-08	2008-09	30-year average	2007-08	2008-09	30-year average
November	96.5	109.5	82.1	67.2	75.6	70.6	11.2	13.3	11.9
December	69.4	120.7	76.4	69.5	59.8	66.7	8.0	9.0	9.0
January	42.7	86.1	57.2	62.0	59.2	67.9	4.1	8.4	7.0
February	67.9	91.0	52.9	61.5	71.4	70.2	5.8	9.0	6.7
March	36.8	49.0	55.8	67.5	74.8	75.9	11.4	8.4	8.0
April	48.0	21.4	58.4	78.5	79.9	79.5	13.6	9.7	11.2
May	40.7	55.3	51.9	75.6	78.3	80.7	15.0	15.8	15.3
June	35.8	8.2	46.6	74.2	76.0	76.5	20.5	21.9	20.2
Sum/Mean	437.8	541.2	481.3	69.5	71.9	73.5	11.2	11.9	11.2

Table 2. Physical and chemical characteristic of the soil at the experimental site (0-20 cm depth)*.

Soil characters	2007-2008	2008-2009
Soil texture	Clay	Clay
Organic matter (%)	3.15	2.93
Phosphorus content (mg/kg)	75.4	70.6
Potassium content (mg/kg)	34.3	38.3
Amount of lime (%)	0.26 (Non-limy)	0.32 (Non-limy)
Salinity (%)	0.7 (Non-salty)	0.8 (Non-salty)
pH	7.00	6.86
Nitrogen content (%)	0.20	0.18
Calcium content (%)	0.68	0.60
Magnesium content (%)	0.11	0.11

* Soil characteristics were determined by the methods of Rowell (1996) and Jones (2001).

Table 3. Mean squares from combined data over years for agronomic and quality traits in 100 oat genotypes.

Source of variation	df	PH	HY	CP	ADF	NDF	TDN	RFV	Ca	K	P	Mg
Years (Y)	1	56095.67**	172.27**	912.66**	57639.68**	212681.09**	96084.35**	9878.79**	0.05	0.26	0.02	0.01
Replication (year)	4	1064.76	35.10	24.61	2962.15	6090.13	5618.14	382.52	0.19	0.79	0.04	0.03
Block (adjustment)	54	5.03	2.04	2.43	9.52	39.96	10.87	2.81	0.08	0.19	0.01	0.01
Genotypes (G)	99	710.24**	12.09**	1617.45**	3573.70**	7929.22**	5956.32**	427.69**	8.00**	30.72**	0.49**	0.52**
G×Y	99	248.23**	2.16**	2.64	7.37	38.29	12.31	1.48	0.01	0.18	0.01	0.01
Error	342	0.02	0.01	1.60	8.34	38.47	13.92	1.89	0.03	0.17	0.01	0.01
Total	599											

PH: Plant height, HY: hay yield, CP: Crude protein, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, TDN: Total digestible nutrient, RFV: Relative feed value, Ca: Calcium, K: Potassium, P: Phosphor, Mg: Magnesium.

*, ** Significant and highly significant at 5% and 1% probability level, respectively; df: Degrees of freedom.

Results and Discussion

The total precipitation was lower than the long-term mean in 2007-08 growing season (437.8 mm) and higher in 2008-09 growing season (541.2 mm) than the long-term mean for the region (Table 1). Means of the relative humidity and the temperature in 2007-08 growing season and the long-term average were lower than in 2008-09 growing season but these values in 2007-08 growing season were similar to the long-term average.

Plant height and hay yield

Analysis of variance combined over two years (Tables 3 and 4) revealed significant differences among genotypes and between years for plant height and hay yield. Plant height was highly variable. Plant height in the second year (115.3 cm) was also higher than that of the first year (95.3 cm). This difference might probably be resulted from the higher cumulative precipitation and other climatic conditions in the second year (Table 3). The combined data over the two years (Table 3) showed that the plant height for genotypes ranged from 76.2 cm (obtained by CROA 43) to 141.2 cm (obtained by Akiyutaka). Akiyutaka, Yeşilköy 330, Cascade, Sisko, Kolpashevskii, Mantaro 15 and Faikbey cultivars were taller (141.2, 132.8, 127.7, 127.2, 124.7, 123.9 and 123.1 cm, respectively), while CROA 43, Lang, Winston, Ebe´ne and Brawn cultivars (76.2, 81.3, 82.6, 84.3 and 86.0 cm, respectively) were shorter (Table 4). Differences in plant height among genotypes are expected due to genetic make-up of the varieties. Plant height was positively correlated with hay yield (Table 5). But, the higher genotypes were more susceptible to lodging. The significant effect of genotypes on plant height in present study is in agreement with previous findings (Chohan et al., 2004; Hussain et al., 2005; Aydın et al., 2010). Mehra et al. (1971), Dhumale and Mishra (1979) and Gill et al. (2013) found that hay yield was positively correlated with plant height. However, Dost et al. (1993) showed that plant height was less important on hay yield.

As sees in Tables 3 and 4, hay yield in the 2008-2009 growing season (second year) was higher than that of first year. This may result from the fact that the rainfall between February and May was much higher in the second year compared with the first year. Moreover, this result could be due primarily to air temperature and other factors. Similar findings were indicated by Maloney et al. (1999), Contreras-Govea and Albrecht (2006) and Aydın et al. (2010).

Data on hay yield showed that hay yield varied significantly among the genotypes (Table 3). The on average highest yielding cultivars were Sisko, Akiyutaka, Longchamp, Sanova, Flämingslord, Matra and Revisor (11.83, 11.77, 11.60, 11.53, 11.53, 11.52 and 11.50 t ha^{-1}, respectively). The lowest hay yields were observed for the cultivars Lang (6.03 t ha^{-1}), Litoral (6.10 t ha^{-1}) and IA91400-2-3 (6.37 t ha^{-1}) (Table 4). The highest hay yielding genotypes generally were European genotypes. The variation in hay yield of genotypes may be attributed to genetic characteristics and adaptability of these varieties to different environmental conditions. The significant variations among oat genotypes for hay yield have already been reported in studies conducted by Anderson and Kaufman (1963), Stuthman and Marten (1972), Chapko et al. (1991), Kim et al. (2006), Aydın et al. (2010) and Gill et al. (2013). Hussain et al. (2005)

also reported that fresh forage yield differed due to differences in leaves per tiller and plant height. The variation in hay yield of genotypes may be attributed to genetic characteristics and adaptability of these genotypes to different environmental conditions.

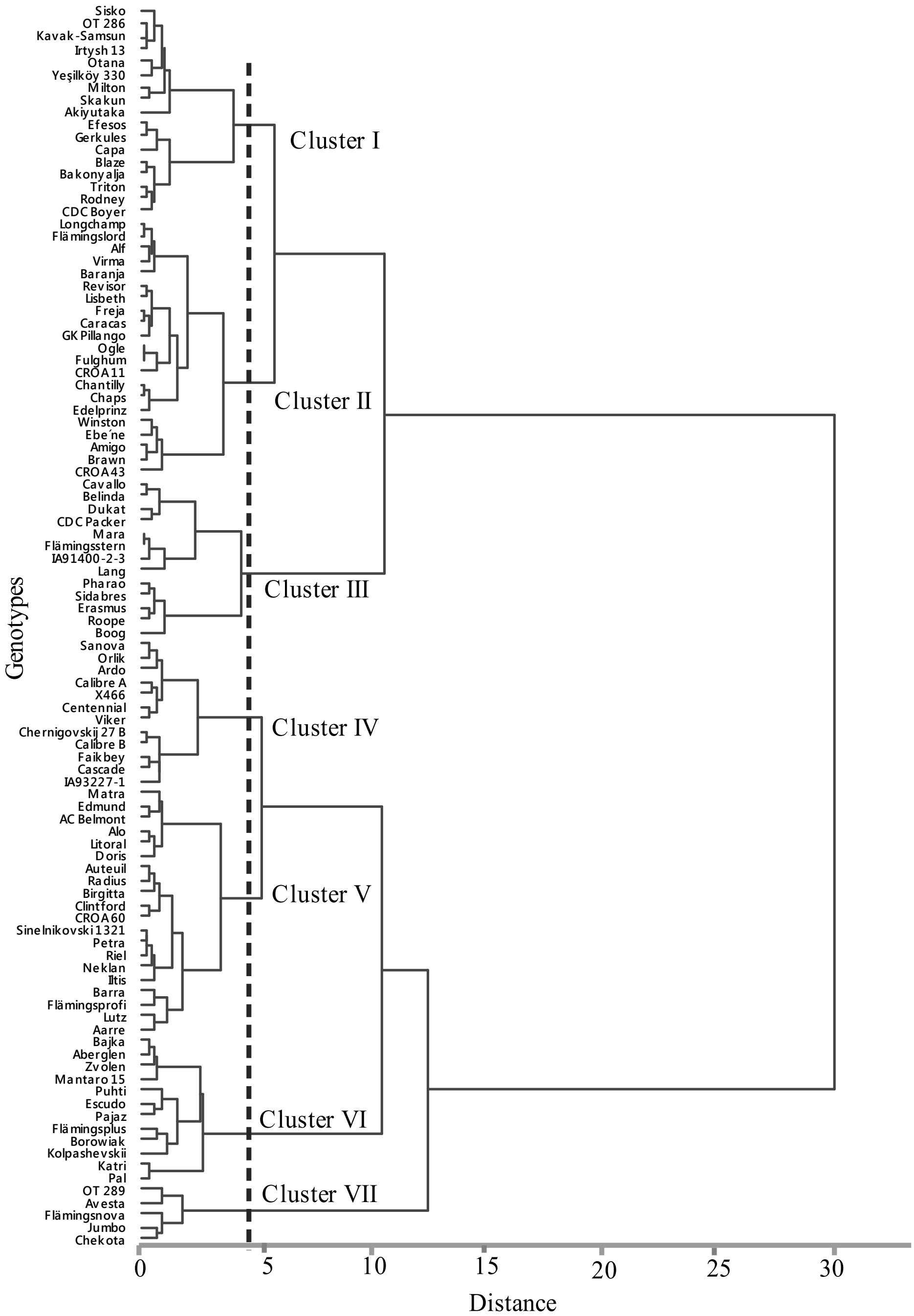

Figure 1. Dendrogram of cluster analysis based on eleven studied variables for oats genotypes.

Table 4. Two-year average values of 100 oat genotypes for plant height, hay yield, quality traits and macro minerals.

Genotype	Origin*	PH (cm)	HY (t ha^{-1})	CP (g kg^{-1})	ADF (g kg^{-1})	NDF (g kg^{-1})	TDN (g kg^{-1})	RFV (%)	Ca (g kg^{-1})	K (g kg^{-1})	P (g kg^{-1})	Mg (g kg^{-1})
Sisko	FI	127.2	11.83	77.0	400.1	610.0	497.0	88.0	5.72	17.25	2.82	1.22
Akiyutaka	JP	141.2	11.77	75.4	388.6	612.6	511.8	89.0	4.59	21.00	3.31	0.60
Longchamp	FR	109.1	11.60	95.4	402.7	603.3	493.6	88.7	5.81	22.74	3.31	0.88
Sanova	DE	109.6	11.53	76.9	392.1	600.0	507.3	90.5	6.49	17.75	2.58	1.02
Flämingslord	DE	108.9	11.53	95.2	401.7	601.0	494.9	89.1	4.22	20.04	3.43	0.99
Matra	NL	94.0	11.52	71.6	358.2	584.5	551.1	97.1	4.86	16.95	3.06	1.14
Revisor	DE	110.9	11.50	87.5	396.8	610.0	501.2	88.4	5.01	24.89	3.53	1.02
Auteuil	FR	104.4	11.40	88.8	371.5	583.2	533.9	95.6	4.16	18.40	3.42	1.15
Efesos	AT	103.2	11.32	85.7	378.5	615.4	524.9	89.8	4.75	19.24	3.21	1.00
Ardo	CZ	121.9	11.31	64.3	382.5	596.6	519.7	92.1	4.78	15.51	2.86	1.07
Edmund	AT	102.1	11.28	88.6	363.9	576.5	543.7	97.7	3.17	16.36	3.23	0.79
Calibre A	CA	111.6	11.27	89.3	383.1	595.3	518.9	92.3	5.53	21.78	3.26	0.67
Cavallo	AT	99.5	11.25	75.9	424.8	627.8	465.1	82.7	7.37	18.32	2.33	1.73
Centennial	US	114.8	11.17	78.3	385.3	585.5	516.1	93.5	6.09	16.07	2.93	1.25
Winston	DE	82.6	11.12	100.0	384.5	600.3	517.1	91.3	3.63	21.41	3.42	1.45
Dukat	PL	113.9	11.10	82.8	418.4	628.7	473.3	83.3	6.63	22.36	2.81	1.34
Chantilly	FR	109.2	11.07	78.6	402.6	618.4	493.7	86.5	2.67	19.05	3.49	0.56
OT 286	CA	114.3	10.97	69.0	397.8	610.0	499.9	88.3	3.66	20.56	3.20	0.73
OT 289	CA	115.3	10.95	99.2	336.9	536.6	578.6	108.6	4.16	16.31	3.27	1.09
Ogle	US	97.5	10.94	79.7	396.4	598.3	501.7	90.2	4.79	18.44	3.28	1.03
Avesta	FR	91.8	10.92	82.7	333.2	522.5	583.3	112.0	5.68	15.91	3.14	1.28
Chernigovskij 27 B	UA	113.1	10.87	78.5	377.9	580.5	525.6	95.3	4.41	19.17	3.52	0.98
Faikbey	TR	123.1	10.72	75.8	380.1	570.0	522.8	96.7	4.77	15.12	3.14	0.99
Alf	DE	99.6	10.70	93.6	400.7	600.0	496.2	89.4	5.71	19.09	2.80	1.20
Milton	US	105.7	10.68	64.0	399.0	620.0	498.4	86.7	4.96	14.17	2.72	1.13
IA93227-1	US	112.4	10.67	62.2	375.7	565.3	528.5	98.1	4.77	16.43	2.96	0.97
X466	US	105.8	10.55	78.6	382.4	600.8	519.8	91.5	4.03	18.41	3.11	0.74
Barra	SE	98.5	10.47	86.9	365.2	607.5	542.0	92.5	5.50	18.64	3.08	1.15
Chaps	US	108.6	10.45	77.3	403.8	616.6	492.2	86.6	4.00	16.23	3.10	0.95

Continue Table 4.

Genotype Origin*		PH (cm)	HY (t ha^{-1})	CP (g kg^{-1})	ADF (g kg^{-1})	NDF (g kg^{-1})	TDN (g kg^{-1})	RFV (%)	Ca (g kg^{-1})	K (g kg^{-1})	P (g kg^{-1})	Mg (g kg^{-1})
Baranja	HR	107.7	10.44	103.0	397.1	591.0	500.8	91.2	5.06	18.16	3.27	0.96
Blaze	US	105.4	10.30	87.0	388.2	615.4	512.3	88.6	5.98	23.12	3.22	0.94
Fulghum	US	99.3	10.30	78.7	396.6	600.0	501.5	89.9	6.56	17.26	2.74	1.59
CROA 11	NZ	88.8	10.30	87.2	403.0	596.7	493.2	89.6	6.66	19.95	2.83	1.62
Edelprinz	AT	107.6	10.30	83.2	406.2	612.1	489.1	87.0	4.55	19.59	3.13	0.95
Mara	LV	102.4	10.27	62.5	407.6	644.9	487.3	82.4	4.55	18.45	2.89	0.80
CROA 43	NZ	76.2	10.24	95.3	388.9	576.6	511.4	94.5	7.39	18.53	2.81	1.78
Sinelnikovski 1321	UA	104.6	10.20	93.2	380.1	595.3	522.8	92.6	5.56	21.58	3.31	1.10
Bajka	PL	110.0	10.18	136.4	370.9	603.8	534.7	92.4	6.72	20.37	3.50	1.33
Amigo	GB	90.4	10.05	89.5	392.2	602.3	507.2	90.1	3.35	18.47	3.43	0.81
Otana	US	120.5	10.04	66.8	402.9	620.5	493.4	86.2	4.12	18.45	3.04	0.91
Ebe´ne	FR	84.3	10.00	93.8	390.3	589.9	509.6	92.2	4.90	20.51	3.36	0.91
Irtysh 13	RU	120.4	9.97	70.9	393.3	610.9	505.7	88.7	4.46	21.05	3.12	0.93
Kavak-Samsun	TR	119.3	9.95	69.0	396.8	614.0	501.2	87.8	3.59	17.29	3.02	0.77
Yeşilköy 330	TR	132.8	9.92	66.1	404.5	623.4	491.3	85.6	6.72	14.84	2.47	1.45
Radius	CZ	99.5	9.82	90.7	374.4	590.4	530.1	94.1	5.41	18.28	3.13	1.05
Capa	UA	119.6	9.81	79.6	381.1	612.8	521.5	89.9	4.36	21.42	3.16	0.85
Freja	SE	103.8	9.75	81.3	394.3	610.1	504.5	88.7	7.53	16.81	2.47	2.01
Puhti	FI	119.3	9.73	118.1	388.1	607.5	512.5	89.8	5.38	16.32	3.39	1.06
Flämingsprofi	DE	106.0	9.65	102.6	371.0	612.9	534.5	91.0	5.11	22.09	3.30	1.22
Gerkules	RU	100.9	9.60	78.2	377.5	617.1	526.1	89.7	4.68	20.44	3.11	1.06
Alo	EE	114.5	9.50	82.4	362.4	579.9	545.6	97.3	4.97	20.15	3.38	1.33
Riel	CA	102.7	9.47	97.0	378.9	600.2	524.3	92.0	4.72	25.07	3.57	1.13
Skakun	RU	109.4	9.30	63.4	393.1	624.1	506.0	86.8	4.18	19.77	3.00	0.92
GK Pillango	HU	109.7	9.23	77.2	395.9	610.0	502.4	88.6	4.38	22.45	3.30	0.95
Belinda	SE	99.4	9.15	71.7	422.6	630.4	467.9	82.6	5.71	19.32	3.10	0.60
Triton	HU	104.6	9.14	84.0	391.6	624.3	507.9	87.0	5.90	19.21	3.01	1.25
Katri	FI	111.5	9.00	121.8	385.3	570.9	516.1	95.9	7.66	18.58	3.37	1.64
Doris	SE	106.1	8.95	75.6	369.6	591.6	536.3	94.5	4.96	19.59	3.05	0.96

Continue Table 4.

Genotype	Origin*	PH (cm)	HY (t ha^{-1})	CP (g kg^{-1})	ADF (g kg^{-1})	NDF (g kg^{-1})	TDN (g kg^{-1})	RFV (%)	Ca (g kg^{-1})	K (g kg^{-1})	P (g kg^{-1})	Mg (g kg^{-1})
Flämingsnova	DE	89.4	8.92	112.9	346.8	554.4	565.8	103.8	3.88	19.88	3.65	1.01
Birgitta	SE	87.4	8.90	94.5	372.5	593.0	532.6	93.9	5.98	20.73	3.28	1.04
Clintford	US	96.4	8.89	82.3	379.3	592.2	523.8	93.2	4.25	16.40	3.07	1.14
Caracas	DE	104.6	8.85	82.5	393.7	606.1	505.2	89.3	5.50	18.90	2.95	1.04
Lutz	DE	104.8	8.84	102.7	368.3	583.9	538.0	95.9	6.85	20.21	3.35	1.36
Virma	FI	106.5	8.80	94.8	401.9	592.0	494.6	90.5	4.93	24.59	3.41	0.68
Flämingsstern	DE	103.5	8.75	62.3	407.6	645.6	487.3	82.3	4.68	16.36	2.98	0.82
Mantaro 15	PE	123.9	8.70	121.1	372.9	613.3	532.1	90.8	7.06	19.18	3.43	1.23
Jumbo	DE	96.1	8.67	94.2	344.5	573.8	568.8	100.6	4.18	17.88	3.17	0.87
Iltis	DE	109.9	8.65	102.4	379.4	585.4	523.7	94.3	4.40	20.45	3.45	0.90
Aberglen	GB	119.9	8.62	134.6	369.1	608.4	537.0	91.9	6.58	17.95	3.55	1.46
Rodney	CA	108.7	8.55	87.4	388.5	627.4	511.9	86.9	6.70	15.72	2.79	1.22
Flämingsplus	DE	88.7	8.51	114.1	391.2	624.4	508.5	87.0	5.79	24.55	3.67	1.27
Bakonyalja	HU	99.9	8.49	83.3	387.2	612.7	513.6	89.2	6.09	18.16	2.99	1.26
Lisbeth	FI	109.5	8.45	88.7	394.3	605.0	504.5	89.4	6.19	21.00	3.15	1.37
Neklan	CZ	105.5	8.35	104.6	384.1	598.6	517.6	91.6	5.65	21.59	3.37	1.17
Calibre B	CA	107.8	8.27	80.4	378.0	574.4	525.5	96.3	5.99	18.02	2.91	0.98
Chekota	TR	108.8	8.20	89.0	342.7	556.8	571.1	103.9	4.83	20.77	3.30	1.21
Escudo	NL	95.3	8.15	113.2	387.6	608.8	513.1	89.7	4.19	17.14	3.57	1.18
Pharao	AT	93.5	8.10	108.6	407.5	622.0	487.4	85.5	8.58	17.82	2.43	2.05
Brawn	US	86.0	8.08	84.5	392.3	599.2	507.0	90.5	5.15	19.82	3.16	0.75
AC Belmont	CA	105.7	8.01	80.6	363.2	572.0	544.6	98.5	4.61	18.08	3.27	0.99
Orlik	CZ	110.2	8.00	66.9	389.2	597.5	511.0	91.2	3.62	15.01	3.09	0.98
Cascade	US	127.7	7.90	71.5	382.1	578.9	520.2	95.0	4.37	18.70	3.00	0.73
Pal	US	113.3	7.85	120.1	385.5	581.1	515.8	94.2	5.69	19.16	3.56	1.07
CDC Boyer	CA	110.1	7.85	83.3	390.5	616.3	509.4	88.2	8.25	13.32	2.43	1.96
Zvolen	SK	100.4	7.83	132.3	371.8	612.8	533.5	91.0	6.50	20.22	3.56	1.32
CROA 60	NZ	89.8	7.80	88.9	382.6	597.2	519.6	92.0	4.37	19.80	3.30	0.86
Kolpashevskii	RU	124.7	7.72	109.3	383.0	636.2	519.0	86.3	5.73	20.10	3.10	1.09

Continue Table 4.

Genotype	Origin*	PH (cm)	HY ($t\ ha^{-1}$)	CP ($g\ kg^{-1}$)	ADF ($g\ kg^{-1}$)	NDF ($g\ kg^{-1}$)	TDN ($g\ kg^{-1}$)	RFV (%)	Ca ($g\ kg^{-1}$)	K ($g\ kg^{-1}$)	P ($g\ kg^{-1}$)	Mg ($g\ kg^{-1}$)
Petra	SE	104.7	7.50	96.3	382.0	593.1	520.3	92.7	4.93	23.95	3.52	1.06
Borowiak	PL	98.3	7.43	120.7	380.7	638.0	522.0	86.4	5.37	23.65	3.54	0.82
Boog	BY	87.2	7.40	104.0	411.6	640.2	482.1	82.6	6.77	19.21	2.95	1.36
Erasmus	AT	93.8	7.15	96.2	413.2	610.8	480.1	86.3	3.19	19.69	3.65	0.77
CDC Packer	CA	101.5	7.08	79.0	412.1	628.3	481.5	84.1	4.88	20.43	3.17	1.00
Viker	EE	118.3	7.05	80.7	386.7	593.2	514.3	92.1	7.75	15.84	2.46	1.61
Aarre	FI	119.3	6.97	104.5	364.5	593.2	542.9	94.9	5.53	19.39	3.26	1.16
Roope	FI	91.6	6.55	104.8	407.7	610.2	487.2	87.1	7.61	19.23	2.92	1.74
Pajaz	YU	91.4	6.50	120.5	381.3	595.9	521.2	92.4	6.17	21.67	3.55	1.26
Sidabres	LT	97.1	6.47	98.1	408.3	623.5	486.4	85.2	7.15	16.57	2.72	1.75
IA91400-2-3	US	102.2	6.37	58.8	411.0	639.4	482.9	82.7	3.69	20.30	2.89	0.95
Litoral	BO	116.8	6.10	84.4	366.9	589.0	539.8	95.2	6.22	18.69	2.94	1.28
Lang	US	81.3	6.03	59.6	412.7	652.4	480.7	80.9	3.14	17.88	3.01	0.79
$LSD_{0.05}$		9.6	0.9	1.20	20.0	29.1	23.2	6.1	0.8	2.4	0.4	0.2
Significance		**	**	**	**	**	**	**	**	**	**	**
Year												
2007-2008		95.9	8.84	93.1	375.4	588.7	528.9	94.6	5.36	19.62	3.16	1.09
2008-2009		115.3	9.92	84.2	397.8	616.0	499.9	87.3	5.24	18.63	3.13	1.15
$LSD_{0.05}$		4.6	0.2	0.3	9.2	11.0	12.1	5.3	0.3	2.1	0.7	0.3
Significance		**	**	**	**	**	**	*	NS	NS	NS	NS
Overall mean		105.6	9.38	88.6	386.6	602.3	514.3	90.9	5.30	19.13	3.14	1.12
CV %		11.4	12.4	7.8	4.7	5.6	5.1	4.9	4.4	5.1	6.2	3.6

*: Country of origin abbreviated by the ISO 3166 country codes, PH: Plant height, HY: hay yield, CP: Crude protein, NDF: Neutral detergent fiber, ADF: Acid detergent fiber, TDN: Total digestible nutrient, RFV: Relative feed value, Ca: Calcium, K: Potassium, P: Phosphor, Mg: Magnesium.
* and **, significant at $P<0.05$ and $P<0.01$, respectively.
NS, not significant at $P<0.05$.
$LSD_{0.05}$, least significant difference at $P<0.05$.
CV, coefficient of variation.

Hay quality

Significant differences were found amongst years and the genotypes regarding crude protein, ADF and NDF, TDN and RFV (Table 3). Crude protein content of forage is one of the most important criteria for hay quality evaluation (Caballero et al., 1995; Assefa and Ledin, 2001). Crude protein content in the first year (89.9 g kg^{-1}) had higher than the second year (87.4 g kg^{-1}). Among genotypes, the crude protein ranged from 58.8 to 136.4 g kg^{-1}. Bajka (136.4 g kg^{-1}), Aberglen (134.6 g kg^{-1}), Zvolen (132.3 g kg^{-1}), Katri (121.8 g kg^{-1}), Mantaro 15 (121.1 g kg^{-1}), Borowiak (120.7 g kg^{-1}), Pajaz (120.5 g kg^{-1}), Pal (120.1 g kg^{-1}) and Puhti (118.1 g kg^{-1}) had significantly higher crude protein content than in the other genotypes in this study (Table 4). The lowest CP content was obtained from genotypes IA91400-2-3, Lang, IA93227-1, Flämingsstern, Mara, Skakun, Milton and Ardo (Table 4). Some researchers pointed out that crude protein content of hay changed among oat genotypes significantly (Ericson et al., 1977; Contreras-Govea and Albrecht, 2006; Kim et al., 2006; Aydın et al., 2010; Gill et al., 2013).

Considering the crude protein contents of oat genotypes in this study (58.8-136.4 g kg^{-1}), in all genotypes except nine genotypes (IA91400-2-3, Lang, IA93227-1, Flämingsstern, Mara, Skakun, Milton, Ardo, Yeşilköy-330, Otana, Orlik, Kavak-Samsun and OT 286, whole forage was higher than the critical level (70 g kg^{-1}) required for optimal rumen function and feed intake in ruminants (Van Soest, 1982). Further, in the present study, none of the high hay yielding genotypes had adequate amount of crude protein needed by cows in the late pregnancy and lactating stages as well as by growing heifers (NRC, 2001), Similarly, only genotypes Longchamp (95.4 g kg^{-1}), Flamingslord (95.2 g kg^{-1}), Winston (100.0 g kg^{-1}) and OT 289 (99.2 g kg^{-1}) had sufficient amount of crude protein needed (90 g kg^{-1}) by the medium frame heifers (NRC, 2001).

Other important quality characteristics for forages are the concentrations of ADF and NDF (Caballero et al., 1995; Assefa and Ledin, 2001). The hay fiber content, ADF and NDF, is a strong predictor of forage quality, since it is the poorly-digested portion in the cell wall. In this study, the values for ADF and NDF in first year were lower than those in second year (Tables 3 and 4). The ADF and NDF showed significant genotypes effects (Table 3). The ADF and NDF contents of the genotypes ranged from 333.2 to 424.8 and 522.5 to 652.4 g kg^{-1}, respectively. Cavallo, Belinda, Dukat, Erasmus, Lang, CDC Packer, Boog, IA91400-2-3, Sidabres, Roope, Mara, Flämingsstern, Pharao, Edelprinz ana Yeşilköy 330 had significantly higher ADF than other genotypes. Similarly, Lang, Flämingsstern, Mara, Boog, IA91400-2-3, Borowiak, Kolpashevskii, Belinda, Dukat, CDC Packer, Cavallo, Rodney, Flämingsplus, Triton, Skakun, Sidabres and Yeşilköy 330 had significantly higher NDF than other genotypes. For both ADF and NDF contents, Avesta, OT 289 and Flämingsnova consistently had the least values. Six ADF and NDF based forage quality standards (prime, 1 (premium), 2 (good), 3 (fair), 4 (poor) and 5 (reject)) have been described for beef cattle (Kononoff, 2005). None of the 100 genotypes qualified for the prime standard (<30% ADF and <40% NDF). Five genotypes (Avesta, OT 289, Chekota, Jumbo and Flämingsnova) met the ADF standart 1 criteria (310-350 g kg^{-1}ADF). Genotypes Avesta and OT 289 met the NDF standard 2 criteria (470-530 g kg^{-1} NDF). In this study, for ADF, seven genotypes with the highest hay yield (Sisko, Akiyutaka, Longchamp, Sanova, Flämingslord, Matra and

Revisor) were within standard 2 of forage quality (360-400 g kg^{-1} ADF). But, for NDF, only five genotypes with the highest hay yield (Longchamp, Sanova, Flämingslord and Matra) met the NDF standard 3 criteria (540-600 g kg^{-1} NDF).

The TDN refers to the nutrients that are available for livestock and are related to the ADF concentration of the forage. As ADF increases there is a decline in TDN which means that animals are not able to utilize the nutrients that are present in the forage. TDN value was higher in first year than in second year (528.9 and 499.9 g kg^{-1} DM, respectively) (Table 4).

The TDN value of the genotypes ranged from 465.1 to 583.3 g kg^{-1}. Genotypes Avesta, OT 289, Chekota, Jumbo, Flämingsnova, Matra, Alo, AC Belmont, Edmund, Aarre and Barra had the highest values for TDN. Kim et al. (2006), Aydın et al. (2010) and Gill et al. (2013) showed that TDN value has significant differences among oat varieties.

The hay RFV was different between genotypes (Table 4). The Avesta had greater RFV than other genotypes. Avesta, OT 289, Chekota, Flämingsnova and Jumbo had >100% RFV. The RFV value was higher in the first growing season than in the second growing season (97.6 and 87.3% DM, respectively). The RFV combines estimated ADF and NDF into a single index. The RFV is an index that is used to predict the intake and energy value of the forages and it is derived from the DDM and Dry matter intake (DMI). Forages with an RFV value over 151, between 150 to 125, 124-103, 102-87, 86-75 and fewer than 75 are considered as prime, premium, good, fair, poor and reject, respectively (Horrocks and Vallentine, 1999). When considering the group of the top 12 genotypes for hay yield, these genotypes qualified for the fair standard (102-87% RFV). The RFV value was calculated from ADF and NDF, the observed differences were reflective of previously described ADF and NDF differences. Thus, a more comprehensive assessment on forage quality should be done for the different oat varieties in the different regions and at different seasons. This conclusion is consistent with the findings of Kim et al. (2006) and Aydın et al. (2010).

The hay Ca, K, P and Mg were significantly affected by genotypes. Ca contents of the genotypes varied from 3.12 (Chantilly) g kg^{-1} to 8.58 (Pharo) g kg^{-1} DM. Tajeda et al. (1985) reported that forage crops should contain at least 3.0 g kg^{-1} of Ca for ruminants. The American National Research Council (NRC, 2001) recommended that forage crops should contain 3.1 g kg^{-1} Ca concentration for beef cattle. Results obtained for Ca concentration in this study were more than these recommended values.

In present study, K contents of the genotypes varied from 13.32 (CDC Boyer) to 25.07 (Riel) g kg^{-1} DM. Differences in K contents of years were not significant. This conclusion is consistent with the findings of Mut et al. (2006), who studied yield and quality of triticale, barley, rye and barley varieties and Aydın et al. (2010), who studied yield and quality of oat genotypes. These results were higher than suggested values of 8.0 g kg^{-1} by Tajeda et al. (1985). But, high K concentration may cause Mg deficiency (Lareda et al., 1983).

P contents of the genotypes changed between 2.33 (Cavallo) to 3.67 (Flämingsplus) g kg^{-1} DM (Table 4). P concentrations of 1.6-2.6 g kg^{-1} for forage crops are recommended for ruminants (NRC, 2001). Results obtained for P concentration in this study were adequate for ruminants.

Mg concentration in the all genotypes was between 0.60 and 2.05 g kg^{-1} (Table 4). Mg concentrations for forage crops are recommended as 2.0 g kg^{-1} for ruminants by

Tajeda et al. (1985) and 1 g kg^{-1} for beef cattle and 2 g kg^{-1} for lactating cow by the NRC (2001). Grass tetany or hypomagnesemic tetany in cattle is caused by an imbalance of K, Ca and Mg in the diet. Mineral imbalances, deficiencies or excess and low bio-availability of essential minerals result in negative economic impacts when animal performance and health are compromised (Van Soest, 1983). Magnesium deficiency may lead to a reduction in weight gain, milk production and conception rate (Stuedemann et al., 1983).

Osman and Nersoyan (1986) pointed out that monocultures of common vetch or cereals do not provide satisfactory results for forage production. Similarly, Lithourgidis et al. (2006) indicated that forage quality of cereal hay is usually lower than that required to meet satisfactory production levels for many categories of livestock. On the other hand, Lawes and Jones (1971) showed that small grain cereals provide high yields in terms of dry weight.

Cluster analysis

Clustering of genotypes based on studied traits is presented in Figure 1. Cluster groups are formed independently of the origin of the genotype. Cluster analysis grouped 100 oats genotypes into 7 clusters as shown in Figure 1. Cluster 1 consisted of 17 genotypes. This cluster was found to have a characteristic feature of high hay yielding and high plant height but low level of protein. Cluster 2 had twenty-one genotypes with a characteristic feature of high hay yielding, high crude protein and moderately or low plant height. Cluster 3 had thirteen genotypes with high level of ADF and NDF, low crude protein content, TDN and RFV values. Cluster 4 had twelve genotypes and this cluster could be characterized by having moderately high values of ADF, NDF, TDN, RFV and plant height. Twenty genotypes constitute cluster 5 and this cluster had a characteristics of moderately protein content, TDN, RFV and P values. Cluster 7 had five genotypes. This cluster is mainly characterized by having high values of TDN and RFV and low values of ADF and NDF. These results could be beneficial in choosing suitable genotypes to be intercrossed for developing optimized cultivars.

Trait correlations

Trait correlations are shown is Table 5. The significant positive association found between plant height and hay yields could deduce that plant height might be an important agronomic character in breeding and selection for forage oat genotypes. This also points out the importance of plant size in predicting hay yield under the given environmental and management conditions. Plant height and hay yield were negatively correlated with crude protein content (Table 5). Gill et al. (2013) indicated that the negative correlations of crude protein to plant height and hay yield may have been due to a dilution effect on the crude protein contents. Hay yield was negatively correlated with Ca content. While Crude protein was negatively correlated with ADF and NDF, it was positively correlated with TDN, RFV, Ca, K, P and Mg. Calcium content was negatively correlated with P. Potassium was positively correlated with P.

Table 5. Pearson correlation coefficients for trait means of 100 oat genotypes tested in two field experiments.

	HY	CP	ADF	NDF	TDN	RFV	CA	K	P	MG
PH	0.27*	-0.21*	-0.02	-0.03	0.02	0.02	-0.01	-0.14	-0.08	-0.16
HY		-0.26**	-0.01	-0.06	0.01	0.05	-0.19*	-0.063	-0.034	-0.17*
CP			-0.28**	-0.17*	0.28**	0.20*	0.36**	0.31**	0.53**	0.30**
ADF				0.90**	-1.00**	-0.95**	0.18*	0.02	-0.45**	0.09
NDF					-0.90**	-0.99**	0.17*	0.19*	-0.35**	0.06
TDN						0.95**	-0.18*	-0.02	0.45**	-0.10
RFV							-0.18*	-0.14	0.37**	-0.07
CA								-0.10	-0.46**	0.79**
K									0.55**	-0.24**
P										-0.46**

[a] For abbreviations see Table 3.
* $P<0.05$
** $P<0.01$

Conclusions

Significant differences between the tested oat genotypes were noticed for the following traits: plant height, hay yield, crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF), Total digestible nutrients (TDN), relative feed value (RFV) and some mineral contents (Ca, K, P and Mg). Generally, the highest yielding genotypes were European origin in this study. Sisko, Akiyutaka, Longchamp, Sanova, Flämingslord, Matra and Revisor were identified as the high hay yield potential genotypes, however, it was not to case for quality traits. Consequently, some form of commercial mineral supplement would be required to oat-based forage production systems or oat should be grown in mixtures with legumes to fulfill livestock needs in effective feeding.

On the other hand, to meet animal needs in oat-based forage systems, crossing high yielding genotypes with genotypes having high quality should be proposed for future breeding programs.

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