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Combining ability study in oat (*Avena sativa* L.) for physiological, quality traits, forage and grain yield

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The experimental material comprised of ten oats (*Avena sativa* L.) genotypes and their 45 F_1 crosses evaluated for physiological parameters, forage quality, green fodder yield plant^{-1} (g) and grain yield plant^{-1}(g). The highest crude protein content was recorded in SKO-208. The lowest Neutral detergent fiber (NDF) was observed in SKO-213. Lowest Acid detergent fiber (ADF) was observed in SKO-204. Lowest crude fiber was observed in SKO-213. Highest ash content was observed in SKO-209. The highest chlorophyll content was recorded in SKO-211. The highest leaf area index (LAI) was recorded in SKO-211. The cross combination SKO-212 × SKO-213 recorded for the highest crude protein content. The cross combination SKO-205 x SKO-207 had lower range of NDF. The lowest range of ADF was observed in cross combination SKO-204 × SKO-211. The cross combination SKO-207 × SKO-212 recorded the lowest crude fibre. For ash content SKO-205 × SKO-212 were found to be superior. The highest chlorophyll content was recorded in genotypes SKO-211 and SKO-208. The cross combination SKO-211 × SKO-212 recorded the highest chlorophyll content. The highest LAI was recorded in genotypes SKO-211 and SKO-208. The highest LAI of cross combination SKO-207 × SKO-211 were found to be superior. The highest forage yield and grain yield observed in SKO-205 and SKO-SKO-208. The cross combinations SKO-211 × SKO-212 and SKO-207 × SKO-211 were found to be superior for forage and grain yield.

Key words: *Avena sativa* L., quality parameters, acid detergent fiber (ADF), neutral detergent fiber (NDF).

INTRODUCTION

Oats (*Avena sativa* L.) is an important *rabi* season cereal fodder crop which is rich in energy, protein, vitamin, phosphorus, iron and minerals for livestock production. In regions with temperate climates, oats are variously spring or winter type depending on sowing time with regard to harshness of climatic conditions. Oats are grown for use as grain as well as forage and fodder, straw for bedding, hay, haylage, silage and chaff. Food uses for oats include oatmeal, oat flour, oat bran, and oat flakes for use as breakfast cereals and ingredients in other food stuffs. Interest in oat hay for the dairy, feedlot and horse industries has grown in recent years. This is mainly due to improvement in oat hay quality brought about by higher quality standards demanded by the export hay market (Lush, 1945). Plant cell walls, containing a digestible and an indigestible fraction are an important element fixing forage quality. Acid detergent fiber (ADF) and Neutral detergent fiber (NDF) are good indicators of fiber contents in forage. ADF content is a measure of the indigestible fraction while NDF content is a measure of the total cell wall fraction.

Oat genotypes that is low in NDF and ADF

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Table 1. Genotypes used in the study with their accession number.

S/N	Genotype	EC number/ Place of collection
1	SKO-204	EC-529089
2	SKO-205	EC-529090
3	SKO-207	EC-529092
4	SKO-208	EC-529093
5	SKO-209	EC-529094
6	SKO-210	EC-529095
7	SKO-211	EC-529096
8	SKO-212	EC-529097
9	SKO-213	EC-529098
10	Sabzaar	Released variety (SKUAST-Kashmir)

should have good forage quality because low NDF is associated with high forage intake and low ADF is associated with high digestibility. Protein content is an important feed factor *per se* with high quality feed having high protein content. Oat protein is nearly equivalent in quality to soy protein, which has been shown by the World Health Organization to be equal to meat, milk, and egg protein. The protein content of the hull-less oat kernel (groat) ranges from 12 to 24%, the highest among cereals (Lasztity, 1999). The state of Jammu and Kashmir in general and Kashmir valley in particular is ideally suited for fodder oats cultivation because of its temperate climate, the oats is grown as *rabi* crop in paddy fields, orchards and on karewa lands. Better grain yield is a bonus for oat cultivars with higher green forage yield as it helps in encouraging farmers to take up seed production and maintain reasonable cost of seed in the production chain.

Therefore, grain yield potential of oat cultivars should be genetically increased. Physiological mechanisms of genetic improvements in grain yield potential are not fully understood. However, it is known that, together with grain yield, some changes were also observed in physiological characteristics controlling the yield during the yield increase process.

Physiological characteristics have significant impacts on growth and development of plants grown in production systems. Therefore, the present work was aimed to determine the physiological characteristics limiting or increasing grain yield in oats by using these characteristics in breeding researches which will definitely speed up the pace improvement as very limited research on this aspect has been done previously.

MATERIALS AND METHODS

The basic material for the present study consisted of 10 diverse genotypes of Oats (*Avena sativa* L.) viz., SKO-204, SKO-205, SKO-207, SKO-208, SKO-209, SKO-210, SKO-211, SKO-212, SKO-213 collected from National Bureau of Plant Genetic Resource (NBPGR) New Delhi (Table 1) and Sabzaar (Released variety) and their 45 F_1 crosses (excluding reciprocals) generated through diallel mating design were evaluated at 3 diverse locations for physiological traits, forage yield its quality and grain yield. The quality parameters viz., crude protein content (CP %) (Jackson, 1973), NDF% (Goering and Vansoest, 1970), ADF% (Goering and Vansoest, 1970), Estimation of ash (%) (AOAC, 1984) and crude fiber (%) (Maynard, 1970) were recorded. Among physiological traits, leaf area index (LAI), was estimated by canopy analyzer (Acuapar LP-80). Chlorophyll content, was taken with chlorophyll meter (SPAD-502, make Konica Minolta Sensing) in the fully expanded top leaf on the tagged plants from each plot. For green fodder yield plant^{-1}(g), individual plant in rows in each experiential plot was cut just above the soil surface at the flowering initiation and green fodder yield per plant was recorded separately. Similarly seed yield plant^{-1} (g), was recorded after weighing the total seeds obtained by threshing 20 tagged plants (from 2 central rows) separately and averaged to a single plant basis. Each experimental plot comprised two rows each of 4 m length. Recommended agronomic package of practices were followed to raise a healthy crop.

RESULTS AND DISCUSSION

The data presented in Table 2 revealed that highest crude protein content (10.67%) of oats among parents was recorded in SKO-208 which was closely followed by SKO-213 (10.52%) and SKO- 204 (10.32%). As regards to fiber quality , the lowest ADF and NDF were exhibited by SKO-213 (31.8%) and SKO-204 (53.7), respectively, Similarly, the lowest crude fiber content was recorded in SKO-213 (22.80) followed by SKO-212 (24.40), Sko-207 (25.20) and SKO- 208 (25.4). Among the 10 genotypes, the highest ask content was observed in SKO-209 (6.90%) while SKO-212 showed the lowest ash content (6.20%) (Table 1). The estimates of forage quality parameters of 45 F1 hybrids were presented in Table 3. It is evident that, the cross combination SKO-212 x SKO-213 and SKO-210 × SKO -213 recorded the highest crude protein content whereas, the cross combinations SKO-205 × SKO-207 and SKO -204 × SKO-211 recorded the lowest range of ADF and NDF respectively. The cross combinations viz., SKO-207 × SKO-212 , SKO -207 × SKO-210 and SKO-210 × SKO-211 recorded the lowest

Table 2. Physiological, forage yield its Quality and seed yield of oats (*Avena sativa* L.) elite genotypes**.**

Parent	Chlorophyll content	LAI	Green fodder yield plant^{-1} (g)	Crude protein content (%)	ADF (%)	NDF (%)	Crude fibre (%)	Ash content (%)	Seed yield plant^{-1} (g)
SKO-204	52.90	3.18	105.7	10.32	33.90	53.70	27.00	6.50	8.18
SKO-205	62.23	5.27	112.11	6.82	39.40	55.40	26.30	6.70	10.70
SABZAR	59.20	2.93	85.13	6.47	39.60	58.40	26.50	6.60	7.31
SKO-207	61.30	3.98	107.13	10.15	32.20	56.50	25.20	6.80	10.67
SKO-208	62.53	5.31	106,18	10.67	32.80	59.70	25.40	6.40	10.70
SKO-209	58.40	3.37	105.11	10.50	33.80	55.90	27.70	6.90	10.69
SKO-210	59.20	4.13	111.05	8.75	38.90	58.80	26.40	6.70	10.66
SKO-211	62.50	5.90	112.81	8.92	38.00	54.70	29.40	6.60	10.68
SKO-212	62.49	4.12	111.07	10.13	34.20	54.10	24.40	6.20	8.57
SKO-213	58.90	3.94	110.71	10.52	31.80	55.80	22.80	6.40	9.92
Mean	58.38	3.85	106.6	9.31	33.05	56.34	25.91	6.49	9.92
SE	± 0.54	± 0.12	±0.47	± 0.27	± 1.41	± 0.36	± 0.32	± 0.04	± 0.27

crude fiber content , where as the cross combination SKO-205 × SKO-212 was found to be superior in terms of ash content. Chlorophyll is a photosynthetic pigment and plays a major role in formation of starch. During the present study it was found that the genotypes SKO-205, SKO-208, SKO-212, SKO-210 and Sabzaar and the cross combinations SKO-205 x SKO- 210, SKO-212 x SKO-213 recorded the highest amount of chlorophyll content (Tables 2 and 3). Among the 10 diverse genotypes and 45 cross combinations of Oat, the highest lea area index was recorded in genotype SKO-211 which was closely followed by SKO-208, SKO-212, SKO-210 and SKO-213 while among cross combination . SKO -212 × SKO -213 and SKO -205 × SKO-210 recorded the highest LAI. Green fodder yield plant $^{-1}$ of 10 parents ranged from 112.1 to 185.13g. The highest green fodder yield was observed from SKO-205, SKO-212 and SKO-210, however, among the cross combinations, the crosses SKO-212 × SKO-213 and SKO-210 x SKO-211 recorded the highest green fodder yield plant^{-1}. Similarly, the grain yield plant^{-1} were found highest in genotypes SKO-208 and SKO-209 and the cross combinations SKO-207 x SKO-211 and SKO-211 × SKO-212 (Tables 2 and 3).

Correlation coefficients at genotype level among the 4 traits viz. LAI, chlorophyll content green fodder yield plant^{-1}, and seed yield plant^{-1} are presented in Table 4. Highly significant (P<0.05) and positive correlations were found between all the traits except green fodder yield plant^{-1} and seed yield plant^{-1} which showed a non significant correlation. The highest significant correlation coefficient was found between LAI, seed yield plant^{-1} (0.7562 %) which was followed by chlorophyll content , seed yield plant^{-1} (8.4456) while the lowest significant correlation coefficient was exhibited by chlorophyll content , green fodder yield plant^{-1} (0.2438)

The best measure related to forage quality is animal productivity, which can be affected by nutrient intake, digestibility and utilization efficiency. The ruminants need a minimum amount of fibers to maintain a good function of rumen and vegetable fibers include cellulose, hemicelluloses, and lignin. Quality forage must have high intake, digestibility and efficient utilization. Plant cell walls, containing a digestible and an indigestible fraction are an important element fixing forage quality. Oat genotypes that are low in NDF and ADF should have good forage quality because low NDF is associated with high forage intake and low ADF is associated with high digestibility. Protein content is an important feed factor *per se* with high quality feed having high protein content. The total mineral content of forage is called ash. The mineral typically determined are calcium and phosphorus. A number of factors must be considered to accurately evaluate forage quality. Relative feed values (RFV) are an index that combines digestibility and potential intake into one number. Chlorophyll is a vital pigment of absorbing, transferring and transforming photosynthetic capability (Yao et al., 2007). There is a close correlation between photosynthetic capability and chlorophyll content.

Studies have also indicated that there is relationship of higher chlorophyll content with resilience to abiotic stress Xie et al. (2011). Giunta et al. (2008) also indicated large variations among cultivars with regard to chlorophyll content and Ashraf (2000) observed that, genotypes with high chlorophyll content had higher photosynthetic impacts and there was a relationship between chlorophyll content and net photosynthesis rate. Present study revealed that, the parents and their cross combination with high chlorophyll content and LAI possesses high green forage and grain yield. Chlorophyll contents and LAI have significant and positive relationship between green fodder and grain yield (Table 4). These findings were in general agreement with the earlier reports of

Table 3. Physiological, forage yield its Quality and seed yield of 45 crosses in oats (*A. sativa* L.)

Crosse combination	Chlorophyll content	LAI	Green fodder yield plant^{-1} (g)	Crude protein content (%)	ADF (%)	NDF (%)	Crude fibre (%)	Ash content (%)	Seed yield plant^{-1} (g)
SKO-204 × SKO-205	62.50	5.31	108.01	8.05	32.60	52.20	28.30	6.60	10.96
SKO-204 × SABZAR	64.70	3.28	110.11	7.70	31.60	52.10	27.70	6.50	12.48
SKO-204 × SKO-207	65.50	4.71	118.3	10.50	32.80	52.60	28.00	6.20	13.39
SKO-204 × SKO-208	67.30	5.38	126.01	10.56	31.90	55.50	20.90	6.90	11.80
SKO-204 × SKO-209	73.30	4.22	122.73	10.70	30.30	57.70	30.20	7.50	12.35
SKO-204 × SKO-210	69.20	5.22	115.44	8.92	36.60	58.80	20.40	5.00	12.28
SKO-204 × SKO-211	65.50	6.10	125.52	10.32	34.50	50.20	21.40	6.50	12.98
SKO-204 × SKO-212	70.00	4.28	124.33	10.51	34.60	52.10	27.60	8.50	12.45
SKO-204 × SKO-213	71.20	4.50	120.33	10.33	31.10	53.30	24.60	6.90	12.16
SKO-205 × SABZAR	62.90	4.10	117.91	7.87	31.40	55.80	26.00	6.40	10.73
SKO-205 × SKO-207	62.50	4.49	124.44	9.10	28.30	52.90	26.40	6.90	13.23
SKO-205 × SKO-208	73.30	6.14	111.37	9.97	34.20	56.50	22.50	6.00	12.45
SKO-205 × SKO-209	66.60	5.01	121.71	10.50	35.90	53.20	29.70	7.20	12.25
SKO-205 × SKO-210	64.10	5.72	126.48	10.52	36.10	57.10	24.40	7.80	11.42
SKO-205 × SKO-211	68.70	6.11	113.12	10.67	33.50	50.90	21.00	6.50	12.69
SKO-205 × SKO-212	54.80	3.48	121.53	10.50	34.70	52.60	24.00	8.70	12.79
SKO-205 × SKO-213	63.10	4.12	123.84	10.52	33.80	54.90	28.00	7.10	11.68
SABZAR × SKO-207	74.59	6.11	125.86	10.15	35.20	52.00	25.80	6.00	13.72
SABZAR × SKO-208	74.60	3.28	119.47	9.45	32.90	56.50	22.50	6.00	12.35
SABZAR × SKO-209	63.40	4.76	118.21	10.50	35.90	53.10	22.30	6.10	12.33
SABZAR × SKO-210	66.40	5.12	108.37	10.32	38.50	57.60	21.70	6.90	12.13
SABZAR × SKO-211	69.50	6.08	116.76	10.33	32.70	55.60	20.40	6.60	12.57
SABZAR × SKO-212	70.30	2.76	123.12	10.32	38.50	57.60	24.70	6.90	12.91
SABZAR × SKO-213	57.90	4.28	120.94	9.80	39.70	59.40	26.50	6.70	10.37
SKO-207 × SKO-208	74.40	4.21	115.82	9.27	38.90	58.40	22.70	6.20	13.54
SKO-207 × SKO-209	60.60	5.31	118.55	10.50	35.90	53.30	26.80	6.70	13.46
SKO–207 × SKO-210	67.80	5.12	124.13	10.67	34.90	55.20	20.60	7.20	13.59
SKO-207 × SKO-211	74.60	8.12	126.48	10.50	36.60	54.80	23.60	6.60	14.08
SKO-207 × SKO-212	66.80	5.24	121.99	9.45	37.60	57.70	17.00	6.60	12.15
SKO-207 × SKO-213	58.60	6.11	116.76	9.97	36.70	57.00	26.30	6.50	11.00
SKO- 208 × SKO-209	69.90	4.12	122.81	10.15	37.20	57.70	23.20	6.40	11.35
SKO- 208 × SKO-210	68.10	7.28	123.01	9.62	36.00	58.50	22.30	7.60	12.20
SKO- 208 × SKO-211	64.50	4.10	115.85	10.50	32.60	54.80	21.60	6.50	12.08
SKO- 208 × SKO-212	63.30	5.64	119.71	10.56	32.50	52.50	25.00	7.50	11.65
SKO- 208 × SKO-213	71.50	5.13	124.55	10.15	33.30	56.30	26.30	6.60	13.56

Table 3. Contd.

SKO- 209 × SKO-210	70.00	7.72	124.99	9.62	36.00	54.40	22.30	7.00	13.32
SKO- 209 × SKO-211	59.50	4.21	117.22	10.58	32.70	55.80	26.60	6.10	12.32
SKO- 209 × SKO-212	72.50	7.98	124.96	9.80	37.50	56.20	26.00	7.10	12.63
SKO- 209 × SKO-213	63.20	5.24	122.77	10.66	33.70	55.40	26.30	6.60	11.25
SKO- 210 × SKO-211	70.40	8.10	125.64	9.62	36.60	54.20	20.40	5.00	12.86
SKO- 210 × SKO- 212	68.60	7.64	123.55	10.15	31.70	54.50	26.50	7.00	12.00
SKO- 210 × SKO-213	69.60	5.11	126.84	10.67	33.80	53.60	25.60	7.60	12.54
SKO- 211 × SKO-212	71.50	6.41	124.37	9.29	36.50	52.40	26.50	6.40	14.07
SKO- 211 × SKO-213	66.10	5.22	121.63	10.50	33.90	53.90	25.70	6.20	12.61
SKO- 212 × SKO-213	60.60	4.20	118.33	10.68	34.10	53.60	24.90	6.30	12.28
Mean	66.36	4.97	120.02	9.97	34.00	54.73	24.22	6.45	12.41
SE	±0.424	±0.107	±0.523	±0.065	±0.327	±0.199	±0.250	±0.083	±0.150

Table 4. Genotypic correlation coefficient for various traits in non-segregating (parents + F_1,s) generation of oats (*A. sativa* L.).

Trait	Leaf area index	Chlorophyll content	Green fodder yield plant^{-1}(g)	Seed yield plant^{-1} (g)
Leaf area Index	-	0.3105**	0.2891**	0.7562**
Chlorophyll content	-	-	0.2438**	0.4406**
Green fodder yield plant^{-1} (g)	-	-	-	0.1301
Seed yield plant^{-1} (g)	-	-	-	-

**, significant at 1% level of significance.

Zhao et al. (2008). Similar relationship was also observed in a previously carried out study Reynolds et al. (1994). Xie et al. (2011) reported that grain yield originated mostly from the photosynthesis and LAI of leaves after heading. Physiological yield-related parameters like LAI, chlorophyll content, leaf area duration and harvest index should be taken into consideration to develop high-yield oat genotypes (Hisir et al., 2012).

Conclusion

The study indicated that, the genotype SKO-208 and SKO-213 had a better nutritional quality due to higher crude protein content and lowest fiber quality parameters. While genotype SKO-207 was better with regards to fiber quality parameter viz., NDF and ADF. SKO-213 was the best for crude fiber and SKO-209 was observed best for ash content. Genotype SKO-208 is identified as superior genotype for most of fodder quality parameters. Parents SKO-208, SKO-207, SKO-213, and SKO-209 need further evaluation across diverse agro-ecological situations to confirm their higher forage yield and nutritional quality while cross combinations need critical evaluation during subsequent generation. Genotypes with high chlorophyll content and LAI were used as selection criteria to improve oat cultivars with higher forage and grain yield.

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