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Research Article

Influence of Flag Leaf Traits on Forage Yield Components and Their Ash Contents in Barley Landraces (*Hordeum vulgare* L.) of South Algeria

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Abstract

Background and Objective: Variability, morphological traits and correlations can be advantageous for breeding programs. The aim of this study was to investigate the influence of flag leaf traits on yield components and their ash content at the soft dough stage and to estimate the variability among genotypes. **Materials and Methods:** The survey was carried out on 11 barley landraces under sub-humid conditions using a randomized design for morphological and agronomic traits and AFNOR method for ash content. One-way ANOVA was used for analysis of variance, Pearson's coefficients for correlations and principal component analysis for multivariate statistical assessment. **Results:** Principal component analysis showed that 5 components absorbed 87.43% of variation. The greater variation among the genotypes was explained mostly by traits of flag leaf, spike and total dry matter yield. Principal correlations showed that the flag leaf area was positively correlated with the spike weight per square meter which had positive correlation with flag leaf length, positive and high correlation with the spike dry weight. Spike fresh weight correlated positively with spike ash content. This last was correlated negatively with ash content of stems and leaves, it was also negatively but highly correlated with flag leaf inclination angle. Heading had a high negative correlation with the spike dry matter content. It was negatively correlated with ash content of stems and leaves but positively with spike ash content. Total dry yield was negatively correlated with flag leaf fresh weight but positively highly correlated with the flag leaf dry matter content. **Conclusion:** A strong diversity was found in the germplasm revealed by very highly significant differences for the majority of the traits studied and particularly for traits of flag leaf, forage yield and spikes. This variability and some links between the flag leaf traits and yield components can help to improve biomass production and ash quality of barley forage.

Key words: Barley germplasm, variability, flag leaf traits, forage yield, ash content

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the major cereal in many dry areas of the world and is vital for the livelihoods of many farmers[1]. It is a major cereal crop primarily grown for its grain, but it also yields valuable forage that can be grazed, cut for hay or silage while still green, or cut after grain harvest as straw[2]. Barley is of utmost importance for livestock feeding, which accounts for about 85% of barley production[3]. High yield is one of the important barley breeding aims[4,5]. Photosynthesis is the primary source of dry matter production and grain yield in crops. The improvements of leaf photosynthesis have occurred with the advance of high-yielding cultivars breeding[6]. Canopy structure of crops directly influences fractional interception of solar energy, thus it affects photosynthesis activity and eventually crop yield[7]. The flag leaf is considered to be a primary source of assimilates for grain filling and grain yield due to its short distance to the spike and the fact that it stays green for longer than the rest of the leaves[8]. The leaf area index or other indices of vegetation have been used in agricultural models for biomass estimation and yield prediction[9]. Leaf area is the main determining factor affecting light interception by crop and biomass production[10]. The leaf inclination angle distribution in crop canopy has attracted more and more attention during the past few years[7]. Previous studies revealed that both phytohormone and non hormone-related genes are involved in regulating the leaf angle[11]. The proper distribution of leaf inclination angles is very important in construction of the 'ideotype' population structure[7].

Many studies around the world have approached the link between the traits linked to the flag leaf with the grain yield and quality that it is on barley[12-14] or on other cereals like wheat[15-18,8,19], rice[20,7,11] and maize[21].

Comprehensive understanding the role of physiological and morphological traits of flag leaf on yield will provide a new insight in crop growth and development[14]. In barley breeding programs, progress in demonstrating that leaf traits improve yield was slow[22].

Stage of maturity at harvesting or grazing can be considered as crucial management practice that determines nutritional quality or either cultivated or natural pasture[23]. Depending on the type of feed needed, the best stage to harvest is either boot of soft dough[24]. Harvesting at heading to milk stage is recommended for optimum quality, although the soft dough stage may yield slightly more forage and still provide reasonably good quality[25].

Ash content represents the total mineral content in foods. Although minerals represent a small proportion of dry matter, often less than 7% of the total, they play an important role from a physicochemical, technological and nutritional point of view[26]. The accumulation of minerals (measured as ash content) in both vegetative tissue and kernels has been proposed an inexpensive and simple way to predict drought adaptation and yield in cereals[27]. Determining the forage's mineral content is important[28]. High ash levels in forage can cause significant challenges when balancing diets for lactating dairy cows[29]. Mineral elements and vitamins are required in small amounts but a deficiency could produce significant reductions in growth and reproduction in otherwise adequately nourished beef cows and calves[28].

Before placing strong emphasis on breeding for nutritional quality characters, the knowledge on the association between yield and yield attributes and also interaction between yield and nutritional quality traits will enable the breeder for simultaneous improvement of yield with nutritional traits[30]. Tingxian[31] indicated that the variation in chemical composition and digestibility of straw in the germplasm collections of cereals crops could presumably be exploited to improve the nutritional value of the straw.

This study was carried out to investigate the influence of flag leaf traits on yield components and their ash content at the soft dough stage but also to evaluate the contribution of the traits studied to explain the variability among the barley landraces.

MATERIALS AND METHODS

Plant material: Eleven cultivars of barley (*Hordeum vulgare* L.) collected from different Saharan regions in Algeria (Table 1) were tested in the experimental station of the National Agronomic Research Institute of Algeria, located in the Mitidja's plain (sub-humid region). Two controls Saïda and Tichedrett (registered Algerian varieties) were used.

Methodology: The experiment design was totally randomized with 2 homogenous plots. Sowing occurred on October, 27, 2016 and the sowing dose was 70 kg ha^{-1}. This experiment was carried out under natural conditions (without irrigation, fertilization and pesticides). The soil was characterized by a sandy clay loam texture.

The parameters studied at the soft dough stage were: Plant height (HPL) (cm), flag leaf length (LLE) (cm), flag leaf width (maximum width) (LWI) (cm), fresh weight of flag leaf (LFW) (g), dry weight of flag leaf (LDW) (g), flag leaf area (ARE) (cm^2), flag leaf dry matter content (DML) (%), flag leaf inclination angle (ANG) (°), fresh weight of spike (SFW) (g), spikes m^{-2} (SPY), dry weight of spike (SDW) (g), spike dry

Table 1: Data of barley genotypes studied

Genotypes	Locality	Local appellation	Province	Geographical location
1	Béchar (two-rowed barley)	-	Béchar	South-Western of Algerian Sahara
2	Ksar Ouled ALI	Selt	Adrar	South-West of Algeria
3	Ksar Hammad	Safira Hammad	Adrar	South-West of Algeria
4	Tsabit Ksar Oudjlane	Azrii	Adrar	South-West of Algeria
5	Tsabit Ksar Hammad	Bourabaa	Adrar	South-West of Algeria
6	In Amguel	-	Tamanrasset	Central Sahara of Algeria
7	Tsabit-Ksar Oudjlane	Safira Oudjlane	Adrar	South-West of Algeria
8	Biskra	-	Biskra	South-East of Algeria (Low Sahara)
9	Tsabit	Ras El Mouch	Adrar	South-West of Algeria
10 (Saïda)	ITGC-Algiers	Saïda	Algiers	Algiers
11 (Tichedrett)	ITGC-Algie	Tichedrett	Algiers	Algiers
12	Haut Oued Righ-Bildet Ammor	Chair de Bildet Ammor	Touggourt	South-East of Algeria (Low Sahara)
13	Haut Oued Righ-Temacine	-	Touggourt	South-East of Algeria (Low Sahara)

matter content (DMS) (%), spike dry weight m^{-2} (SWS) ($g\ m^{-2}$), spike ash content (SPH) (%), ash content of whole plants (PLH), ash content of stems and leaves (ALS) and total dry matter yield of whole plants (TDY) ($t\ ha^{-1}$). In addition of these traits, the heading date (DEP) was noted at the emergence of 50% of the spikes for each cultivar.

A random selection of 10 plants was done on 2 plots (five plants/plot were chosen from the central parts of each row) of the test to study the following agro-morphologic characters: HPL, LLE, LWI, LFW, LDW, ARE, DML, SFW, SDW and DMS.

For the other traits (SPH, PLH, ALS, SPY, SWS and TDY), two repetitions/cultivar were considered. For the flag leaf inclination angle, 20 measures were taken on the 2 plots using a protractor.

The flag leaf area was calculated as the following formula: Area = length$\times$width$\times$k where k (equal to 0.64) is a multiplying factor generally used for barley as indicated by Sestak *et al.*[32]. After cutting, the flag leaves (green) and the spikes were kept in a cool box for conserving their humidity and were quickly measured and/or weighed to avoid losses in humidity.

The yield was determined on 2 m^{-2} chosen from the middle rows of the plots. All yield calculations were based on dry matter content at the soft dough stage by drying in a forced draught oven at 105°C for 48 h. The total dry matter yields (TDY) obtained, were converted into t ha^{-1}. Spike ash content, ash content of stems and leaves and ash content of the whole plant (stems, leaves and spikes) expressed in dry weight basis (%) were obtained according to the AFNOR[33] method. To determine ash content of each one of these last parameters, 3 g of powder were extracted from 2 representative samplings of the total parcel yields.

Statistical analysis: The analysis of variance (one-way ANOVA) was performed by Fisher's least significant difference (LSD) method at 5% level to test the significance difference between means.

One-way analysis of variance (ANOVA) was made by the Gen Stat Discovery (Edition 3, Stat Soft Inc.) to analyze these quantitative characters (HPL, LLE, LWI, LFW, LDW, DML, SFW, SDW, SWS, DMS, ARE, SPH, PLH, ALS, SPY and TDY) (Table 2).

Principal component analysis (Table 3) and Pearson's correlations (Table 4) were obtained by Statistica (Data analysis Software System, version 6, Stat Soft Inc.) and were performed basing on the mean values of eighteen traits (HPL, LLE, LWI, LFW, LDW, ARE, DML, ANG, SFW, SDW, SWS, DMS, SPH, PLH, ALS, SPY, TDY and DEP). The mean values of all the traits studied are mentioned on Table 5.

RESULTS

Germplasm variability: Analysis of variance (Table 2) showed that differences among the genotypes were very highly significant ($p<0.001$) for: HPL, SDW, SFW, LLE, LFW, LDW, DMS, DML, PLH, ALS, SPY, SWS and ARE, highly significant ($p<0.01$) for SPH witch attest the presence of a big variability in the germplasm. Differences among genotypes were no significant for LWI and TDY.

Principal component analysis (Table 3) showed that five components absorbed 87.43% of total variation. The first component with 39.35% of variation was correlated to the following traits: LDW, LFW, ANG, ARE, SPH, LWI, SFW, LLE, SDW and TDY. The second component with 20.72% of total variation was correlated with: DMS, SWS and DEP. Characters ALS, DML and PLH were correlated to the third component which represented 11.74% of total variation. SPY was correlated to the fourth component accounting 9.3% of total variation. The HPL was correlated to the fifth component representing 6.33% of total variation.

Correlated parameters: The flag leaf area was positively and very highly correlated with the flag leaf's length and width and was highly correlated with flag leaf fresh and dry weights (Table 4). Flag leaf area was also correlated positively with

Table 2: ANOVA of flag leaf and other agronomic traits in 11 barley landraces and two controls

Traits	Minimum value	Maximum value	Mean	SEM	LSD	CV (%)	Probability
HPL	97.8	120.4	108.24	1.7	4.8	5	<0.001
ARE	17.57	31.87	24.85	2.3	6.45	29.3	<0.001
SFW	2.26	5.3	3.35	0.31	0.86	29	<0.001
LFW	0.09	0.36	0.24	0.03	0.08	37.1	<0.001
SDW	0.88	1.93	1.23	0.13	0.37	33.8	<0.001
LDW	0.04	0.11	0.07	0.01	0.02	35	<0.001
LLE	11.69	19.2	15.42	1.3	2.58	18.9	<0.001
LWI	1.39	1.73	1.58	0.06	0.18	13.2	0.095
DMS	31.54	43.53	36.66	0.9	2.6	8	<0.001
DML	18.98	45.85	35.64	2.4	6.67	21	<0.001
SPY	280.5	540	354.5	26.47	57	7.5	<0.001
SPH	3.28	5.1	4.1	0.31	0.66	7.5	0.002
PLH	6.75	8.35	7.56	0.27	0.59	3.6	<0.001
ALS	2.22	4.65	3.52	0.41	0.88	11.6	<0.001
SWS	258	690	430	60	129.8	14	<0.001
TDY	0.8	1.43	1.02	0.23	0.49	22.4	0.305

SEM: Standard Error of Means, LSD: Least Significant Differences of means at 5% level, CV: Coefficient of Variance, Very highly significant at p<0.001, highly significant at p<0.01, No significant at p>0.05, HPL: Plant height) (cm), ARE: Flag leaf area (cm^2), SFW: Fresh weight of spike (g), LFW: Fresh weight of flag leaf (g), SDW: Dry weight of spike (g), LDW: Dry weight of flag leaf (g), LLE: Flag leaf length (cm), LWI: Flag leaf width (cm), DMS: Spike dry matter content (%), DML: Flag leaf dry matter content (%), SPY: Spikes per m^{-2}, SPH: Spike ash content (%), PLH: Ash content of whole plants (%), ALS: Ash content of stems and leaves (%), SWS: Spike dry weight m^{-2} (g m^{-2}), TDY: Total dry matter yield of whole plants (t ha^{-1})

Table 3: Principal component analysis (PCA) of 11 barley landraces and two controls based on eighteen traits

Parameters	PC1	PC2	PC3	PC4	PC5
Eigen values	7.08	3.73	2.11	1.67	1.13
% of variance	39.35	20.72	11.74	9.3	6.33
Cumulative %	39.35	60.07	71.8	81.1	87.43
Characters					
ARE	0.799	-0.442	-0.204	0.288	0.045
SFW	0.760	-0.166	0.316	-0.471	0.127
LFW	0.888	0.211	-0.205	0.231	0.021
SDW	0.605	-0.533	0.201	-0.484	0.073
LDW	0.898	-0.098	0.288	0.168	-0.139
LLE	0.740	-0.497	-0.116	0.324	0.134
LWI	0.777	-0.199	-0.469	-0.033	-0.178
DMS	-0.293	-0.833	-0.129	-0.105	-0.170
DML	-0.424	-0.562	0.577	-0.133	-0.100
HPL	-0.007	-0.200	-0.125	-0.196	-0.914
DEP	0.529	0.657	0.206	-0.054	0.025
ANG	-0.869	0.022	0.007	-0.095	0.095
SPH	0.792	0.279	0.095	-0.360	0.061
PLH	-0.087	-0.428	-0.563	-0.384	0.346
ALS	-0.532	-0.480	-0.635	0.074	0.091
SWS	0.423	-0.792	0.277	0.017	0.104
SPY	-0.089	-0.398	0.376	0.756	0.014
TDY	-0.582	-0.341	0.461	-0.101	0.128

ARE: Flag leaf area (cm^2), SFW: Fresh weight of spike (g), LFW: Fresh weight of flag leaf (g), SDW: Dry weight of spike (g), LDW: Dry weight of flag leaf (g), LLE: Flag leaf length (cm), LWI: Flag leaf width (cm), DMS: Spike dry matter content (%), DML: Flag leaf dry matter content (%), HPL: Plant height) (cm), DEP: Days to heading (days), ANG: Flag leaf inclination angle (°), SPH: Spike ash content (%), PLH: Ash content of whole plants (%), ALS: Ash content of stems and leaves (%), SWS: Spike dry weight m^{-2} (g m^{-2}), SPY: Spikes m^{-2} and TDY: Total dry matter yield of whole plants (t ha^{-1})

spike dry weight per square meter. The flag leaf inclination angle was negatively highly correlated with flag leaf area, flag leaf's fresh and dry weights, flag leaf width and spike ash content and had also negative correlations with flag leaf length and spike fresh weight.

Heading date showed a negative highly correlation with the spike dry matter content, a positive correlation with the spike ash content, a negative correlation with ash content of stems and leaves. This last correlated negatively with leaf dry weight and positively with ash content of whole plant.

The total dry matter yield per hectare had a negative and significant correlation with the flag leaf fresh weight but high positive correlation with the flag leaf dry matter content. No significant correlations existed between plant height, spikes m^{-2} and all other traits.

Table 4: Correlation matrix on eighteen traits of 11 barley landraces and two controls

	ARE	SFW	LFW	SDW	LDW	LLE	LWI	DMS	DML	HPL	DEP	ANG	SPH	PLH	ALS	SWS	SPY
SFW	0.49																
LFW	0.72*	0.51															
SDW	0.53	0.9***	0.32														
LDW	0.77*	0.67*	0.74**	0.53													
LLE	0.98***	0.47	0.65*	0.53	0.74**												
LWI	0.81***	0.48	0.7**	0.47	0.61*	0.69**											
DMS	0.09	-0.11	-0.42	0.34	-0.23	0.14	-0.05										
DML	-0.23	-0.07	-0.73**	0.13	-0.11	-0.15	-0.42	0.49									
HPL	0.02	-0.02	-0.08	0.08	0.06	-0.07	0.28	0.28	0.16								
DEP	0.07	0.41	0.51	0.04	0.39	0.02	0.27	-0.8**	-0.47	-0.12							
ANG	-0.69**	-0.56*	-0.74**	-0.42	-0.82***	-0.59*	-0.73**	0.27	0.27	-0.06	-0.4						
SPH	0.38	0.69**	0.61*	0.44	0.67*	0.32	0.49	-0.48	-0.3	-0.04	0.6*	-0.75**					
PLH	0.14	-0.01	-0.19	0.17	-0.3	0.13	0.26	0.31	0.08	-0.00	-0.38	0.00	0.07				
ALS	-0.06	-0.52	-0.43	-0.21	-0.64*	-0.07	0.03	0.55	0.11	0.11	-0.63*	0.43	-0.68*	0.63*			
SWS	0.6*	0.56*	0.17	0.78**	0.46	0.67*	0.3	0.54	0.34	0.02	-0.17	-0.33	0.11	0.13	-0.00		
SPY	0.28	-0.24	-0.15	-0.04	0.10	0.38	-0.13	0.38	0.45	-0.09	-0.31	0.00	-0.42	-0.05	025	0.43	
TDY	-0.37	-0.12	-0.68*	-0.06	-0.38	-0.31	-0.51	0.18	0.73**	0.02	-0.36	0.51	-0.5	0.12	0.28	0.07	0.33

Non-significant at $p>0.05$, significant at *$p<0.05$, highly significant** at $p<0.01$, very highly significant*** at $p<0.001$, ARE: Flag leaf area (cm^2), SFW: Fresh weight of spike (g), LFW: Fresh weight of flag leaf (g), SDW: Dry weight of spike (g), LDW: Dry weight of flag leaf (g), LLE: Flag leaf length (cm), LWI: Flag leaf width (cm), DMS: Spike dry matter content (%), DML: Flag leaf dry matter content (%),HPL: Plant height) (cm), DEP: Days to heading (days), ANG: Flag leaf inclination angle (°), SPH: Spike ash content (%), PLH: Ash content of whole plants (%), ALS: Ash content of stems and leaves (%), SWS: Spike dry weight m^{-2} ($g\ m^{-2}$), SPY: Spikes m^{-2} and TDY: Total dry matter yield of whole plants ($t\ ha^{-1}$)

Table 5: Mean values of all traits studied on 11 barley landraces and two controls at the soft dough stage

Genotypes	HPL	ARE	SFW	LFW	SDW	LDW	LLE	LWI	DMS	DML	ANG	SPH	PLH	SPY	ALS	TDY	SWS	DEP
1	106	19.6	2.43	0.34	0.88	0.06	14.47	1.39	36.11	18.98	17	3.97	7.13	540	3.16	1.03	477	119
2	105.55	25	3.7	0.18	1.6	0.06	15.7	1.59	42.61	38.93	67.5	3.98	8.3	306.2	4.31	0.98	495	107
3	112.8	31.87	3.44	0.29	1.36	0.09	18	1.73	38.92	33.56	27.5	4.27	8.35	299.8	4.65	0.92	409	107
4	111	20.3	2.47	0.13	0.92	0.06	12.56	1.53	36.69	45.85	52	3.54	7.42	396.2	3.88	1.27	344	112
5	111.6	26.66	3.54	0.18	1.55	0.07	16.68	1.59	43.53	44.14	45.5	4.08	8.24	445	4.17	1.07	690	107
6	103	23.9	2.8	0.13	0.98	0.05	15.37	1.55	34.88	42.65	80.5	3.4	8.02	395	4.62	1.43	385	119
7	116.15	17.57	2.26	0.09	0.92	0.04	11.69	1.51	40.46	40.37	86.5	3.28	7.03	280.5	3.74	1.08	258	109
8	103.51	31.61	3.15	0.31	1.22	0.11	19.2	1.62	38.15	36.57	40	3.82	6.75	467.5	2.93	0.84	570	122
9	101.7	25.23	3.6	0.36	1.18	0.07	15.36	1.59	32.51	20.39	50.3	4.12	7.35	290	3.22	0.87	342	127
10	120.4	26.62	3.23	0.31	1.04	0.09	15.84	1.66	31.97	29.82	38.8	4.72	7.62	305.2	2.9	0.8	316	139
11	97.8	21.52	2.98	0.21	0.95	0.06	13.41	1.59	31.54	30.91	44.4	4.58	7.44	285	3.21	0.8	272	139
12	113.4	27.75	5.3	0.28	1.93	0.1	16.3	1.68	36.16	37.45	35	4.5	7.25	307.5	2.74	1.07	594	141
13	104.2	25.44	4.6	0.25	1.52	0.11	15.91	1.56	33	43.66	36	5.1	7.32	290	2.22	1.1	440	126

HPL: plant height) (cm), ARE: flag leaf area (cm^2), SFW: fresh weight of spike (g), LFW: fresh weight of flag leaf (g), SDW: dry weight of spike (g), LDW: dry weight of flag leaf (g), LLE: flag leaf length (cm), LWI: flag leaf width (cm), DMS: spike dry matter content (%), DML: flag leaf dry matter content (%), ANG: flag leaf inclination angle (°), SPH: spike ash content (%), PLH: ash content of whole plants (%), SPY: spikes per m^2, ALS: ash content of stems and leaves (%),TDY: total dry matter yield of whole plants (t/ha), SWS: spike dry weight per m^2 (g/m^2), DEP: days to heading (days)

Principal traits's characteristics: The highest mean value of ARE was registered at the genotype 3 from Adrar. This same genotype had the highest mean value of LWI and the highest mean value of PLH. The genotype 12 from Touggourt presented the highest mean values of SDW also the highest number of DEP. The highest mean values of DMS and SWS were that of the genotype 5 from Adrar. This genotype had, beside genotypes 2 and 3, the lowest DEP. The genotype 7 had the highest ANG but had the lowest mean values of: ARE, SFW, LFW, LLE, LDW, SPY, SWS and SPH. The genotype 13 (from Touggourt) presented the highest value of SPH and the lowest value of ALS. The highest TDY was noted at the genotype 6 from Tamanrasset and the lowest values concerned the controls. The highest SPY was registered in 2 rowed barley which presented the lowest mean values of ANG, DML and SDW (Table 5).

DISCUSSION

Differences between the genotypes studied were very highly significant for the majority of the traits studied. Thus, a great variability exist within the germplasm. Sharma *et al.*[34] mentioned that seeking and incorporating genetic diversity for traits the breeder thinks are potentially yield enhancing may be an investment in the present as well as in the future.

According to Zeidan[35], several researchers reported that barley cultivars vary in plant height, number of spikes m^{-2}, flag leaf area and protein content of grain. High significant differences were found for leaf length and leaf area by Lonbani and Arzani[36] on triticale and wheat. However, Bilgili *et al.*[37] found that differences among 33 triticale lines were no significant for leaf length. In our case, no significant differences were found among the genotypes for the flag leaf width. Similar results were found on triticale and wheat by Lonbani and Arzani[36] and on wheat by Wahidy *et al.*[19].

Principal component analysis showed that the greatest variation among the genotypes was explained by traits of flag leaf, spike and total dry yield. This variability could be exploited for breeding programs. As indicated by Ogunniyan and Olakojo[38], adequate variability provides options from which selections are made for improvement.

Composition of minerals in spikes, whole plant also stems and leaves showed a great variability among the genotypes. In durum wheat, significant genotype variation was detected for kernel ash content by Bogale and Tesfaye[27]. Tingxian[31] reported that Kshanika and coworkers studied the chemical composition and *in vitro* organic matter digestibility of nine varieties of rice straw, they found that wide variability existed in the composition of different plant parts. According to Tingxian[31], variation in chemical composition and digestibility of straw in the germplasm collections of cereals crops could presumably be exploited to improve the nutritional value of the straw.

Results of this study done at the soft dough stage showed many correlations between traits related to flag leaf, spikes and total dry matter yield. Sharma *et al.*[34] indicated that development of the ideotype concept has focused the attention of plant physiologists and breeders on the identification of simple morphological characters which influence physiological processes determining yield.

The flag leaf area was very highly correlated with the flag leaf's length and width. These two last were positively highly correlated between them. Liu *et al.*[14] found a similar result in barley with high correlations between all these three morphological traits.

Leaf area was also positively and significantly correlated with the spike dry weight per square meter. Association of flag leaf area with kernel number and average kernel weight was demonstrated by Smocek[39]. As confirmed by Reynolds *et al.*[40] and Isidro *et al.*[41], new research reinforces the importance of spike dry weight (g m^{-2}) at anthesis in yield determination. Biswal and Kohli[42] indicated that flag leaves are the main organ for photosynthesis, providing the major assimilate source required for plant growth and panicle development also sensing environment signals for adaptation. On the other hand, it has been highlighted that the high spike dry weight per square meter at anthesis is closely correlated with the number of fertile florets per square meter, as indicated by Isidro *et al.*[41]. In wheat, Smocek[43] found that the maximum genetic gain was attained when flag leaf area was included with yield components. The flag leaf length was positively and significantly correlated to the flag leaf width. The same result was found by Xue *et al.*[5] in barley.

The flag leaf angle inclination had negative high correlation with the spike ash content and negative correlation with the spike fresh weight. Vanavichit[44] reported that erect leaf habit was advantageous for enhancing photosynthetic efficiency and has been proved by many works for rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), forage grasses and sugar beet (*Beta vulgaris* L.). In rice, Yoshida[45] indicated that leaf erectness can be used as an effective selection criterion for enhancing grain yield. On their side, Sharma *et al.*[34] indicated that characters such as leaf inclination and leaf shape could be rapidly modified by selection to increase crop photosynthesis and yield.

The flag leaf dry matter content was positively and highly correlated with the total dry matter yield. On rice, grain filling percentage and grain m^{-2} were found to be linearly correlated with leaf dry matter at the heading stage[46]. The total dry matter yield per hectare had a negative and significant correlation with the flag leaf fresh weight. Yang and Hwa[47] indicated that leaf traits, such as leaf thickness, size and shape, leaf number and orientation, are key factors influencing biomass formation.

Near the level of signification, a negative correlation (r^2 = -0.5) was found between the spike ash content and the total dry matter yield. In barley, the relationships between ash content of grain and grain yield were found to be significantly negative in rainfed conditions by Voltas *et al.*[48]. On maize, Milenkovic *et al.*[49] found that the lowest phenotypic correlation relationship was found between yield and crude ash content.

The spike ash content was positively and significantly correlated with heading. The same found was observed in the case of proteins by Kren *et al.*[50] in which barley grain protein content was inversely related to early growth parameters. According to Jadhav *et al.*[51], nutrient compositions of barley can vary depending on genetic and environmental factors.

The spike dry matter content was negatively and highly correlated with heading. In their study on wheat, Munir *et al.*[52] found negative correlations between days to heading and the grain weight/spike. The spike ash content was positively highly correlated with spike fresh weight, positively correlated with leaf dry weight and heading but was negatively highly correlated with the flag leaf inclination angle. The accumulation of mineral or ash content in both vegetative tissues and kernels have been proposed as inexpensive and simple ways to predict yield and genotypic adaptation to drought in different C_3 cereals[53].

Ash content of stems and leaves was negatively correlated to days to heading. Siefers *et al.*[54] indicated that the crude protein and ash contents were higher for the early-heading than the mid-dough cereals.

Ash content of whole plant (spikes, stems and leaves) varied between 6.75% (genotype 8) and 8.35% (genotype 3). According to Hoffman[55], the normal ash content of legume-grass forages is near 9.0% (DM basis). Ideally, ash should not exceed 8.5%[56]. In a study taken by Guney *et al.*[57], ash content of barley forage was 6.4% at heading, 6.04% at seed formation stage and 6.4% at mature stage. On a table of composition of cereal straws cited by Tingxian[31], ash content was 6.4% for barley, 4.4% for oat, 19.4% for rice, 6% for sorghum, 5.6% for triticale and 6.4% for wheat.

In this study, all the genotypes presented ash of whole plant as following: 3 (8.35), 2 (8.3), 5 (8.24), 6 (8.02), 4 (7.42), 9 (7.35), 13 (7.32), 12 (7.25), 1 (7.13), 7 (7.03), 8 (6.75) beside the controls 10 (7.62) and 11 (7.44). The same genotypes among others studied by Rahal-Bouziane *et al.*[58], presented the crude protein (%) of whole plants at the dough stage like this: 9 (8.7), 12 (8.61), 4 (7.75), 6 (7.4), 7 (6.45), 3 (6.13), 13 (5.72), 8 (5.45), 2 (5.38), 5 (5.33), 1 (5.27) and the controls: 11 (8.95) and 10 (7.29), for the crude fiber (%), they were classified like this: 12 (34.46), 2 (32.37), 9 (31.45), 6 (31.23), 5 (31.03), 13 (30), 3 (27.28), 1 (23.48), 4 (22), 8 (18.98), 7 (15.29) and the controls: 10 (29.11) and 11 (24.63).

In the light of results of the 2 trials, it appears that generally, genotypes with the lowest values of crude fiber in the first experiment taken by Rahal-Bouziane *et al.*[58] were those presenting the lowest values of ash content in the second trial and vice versa, which suggesting that these two parameters would be positively correlated. Association between soluble fiber and ash was found by Schweizer and Wursch[59] and by Frolich and ASP[60].

CONCLUSION

- Improving grain and forage yields in barley is a strategic objective both for human and animal feed
- A great variability was found among genotypes for the majority of the traits studied and particularly for those related to the flag leaf, spike ash content, spike dry weight and total dry matter yield
- Interesting correlations were found between traits of flag leaf and forage yield components and their ash content
- Improvement of yield and ash forage quality could be possible by some morphological traits related to the flag leaf because of interesting links existing between them

SIGNIFICANCE STATEMENTS

This study showed that barley landraces exhibited a strong variability for traits related to the flag leaf, the forage yield and its ash content which is promising for genetic improvement. Beside this variability, results found especially on correlations between the flag leaf traits and forage yield components and their ash content via this study, which opens new perspectives for genetic improvement in favor of barley as forage in terms of yield and ash content at the soft dough stage.

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