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Optimizing laboratory indicators of the nutritive value of straw in decentralized barley straw quality evaluation

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SUMMARY - In sheep fed diets containing *ad libitum* barley straw, body weight change is closely correlated with straw intake. We are finding that it is more effective to select genotypes for straw intake using calibrated indirect tests than by conducting intake trials with sheep. Not only are the tests cheaper, but the test results are more heritable, even when their genotypic correlation with intake is allowed for. Of the tests, Near Infrared Reflectance Spectroscopy is the most effective, followed by *in sacco* dry matter loss, acid detergent fibre, pair-preference tests in sheep, and *in vitro* gas production with rumen fluid.

Key words: Laboratory methods, nutritive value, barley straw, sheep.

RESUME - *"Optimiser les indicateurs de laboratoire de la valeur nutritionnelle des pailles pour une évaluation décentralisée de la qualité des pailles d'orge". Chez des ovins recevant un régime contenant de la paille d'orge* ad libitum, *le changement de poids corporel est étroitement corrélé à l'ingestion de paille. Il est montré qu'il est plus efficace de sélectionner des génotypes pour l'ingestion de paille en utilisant des tests indirects calibrés qu'en menant des essais d'ingestion sur ovins. Ces tests sont non seulement moins onéreux, mais les résultats des tests sont plus héritables, même lorsque leur corrélation génotypique avec l'ingestion est permise. Parmi ces tests, la spectroscopie par réflectance infrarouge proche est la plus efficace, suivie par la perte de matière sèche* in sacco, *la fibre acide-détergente, les tests d'ingestion comparative chez les ovins, et la production de gas* in vitro *avec les fluides ruminaux.*

Mots-clés : *Méthodes de laboratoire, valeur nutritionnelle, pailles d'orge, ovins.*

Introduction

In the semi-arid parts of West Asia, the barley crop is used in diverse ways, according to the feeding system and crop-growing conditions. It may be used as a winter pasture, as standing hay, and (if the spring is favourable) as grain, stubble and straw. Barley straw is a storable feed useful for drought and winter feeding. When springs are wet and cold, straw and stubble are plentiful but poor in feeding value. Farmers expect new genotypes of barley to have straw with genetically good feeding value. Increased nutritive value of straw will have impact through reducing the quantity of energy supplements that are needed in sheep's diets and through making it more worth while to store straw for future use.

Materials and methods

In each of 8 years at Tel Hadya (36º56'E, 36º10'N, altitude 300 m), we grew and tested a total of 44 straw samples, representing between 3 and 9 genotypes. Annual rainfall totalled 233-504 mm during the 8 years. Rainfall in the February-April period totalled 57-198 mm and maximum air temperature in the March-May period averaged 22.9-27.6ºC. Mean voluntary straw DM intake was 590-1530 g/d, for a standard sheep of metabolic body size 20.0 kg $W^{0.75}$ (weighing approximately 54 kg).

We carried out the following tests on straw samples to indicate nutritive value:

(i) Voluntary straw intake (quantity of straw offered = 1.2 × intake, 11-day adaptation period with 10-day measurement period, 7 years, 3-8 sheep). This test was highly correlated with weight gain and therefore used as the benchmark against which other tests were compared.

(ii) Within-year pair-preference "palatability" (6 years, replicated 30-40 times).

(iii) Loss of DM from nylon fabric bags suspended in the sheep's rumen for 0, 8, 24, 48, or 72 hours (8 years, replicated 6-8 times); also the *a*, *a+b*, *c* and *lag* parameters of the DM loss curve.

(iv) *In vitro* gas production from 200 mg straw for up to 96 hours (6 years, replicated 6 times); parameters of gas production using 3- and 4-parameter models (France *et al.*, 1993).

(v) Conventional feed evaluation tests: organic matter, crude protein, detergent fibres (NDF, ADF, ADL) (8 years, replicated 3-5 times).

(vi) Energy required to grind 5-gram samples in a small laboratory mill (6 years, replicated 6 times).

(vii) Near Infrared Reflectance Spectroscopy (NIRS) measurements (8 years, 3 replicates) in the range 1130-2468 nm, optimized for the prediction of voluntary intake (2, 12, 7, 1 in ISI notation).

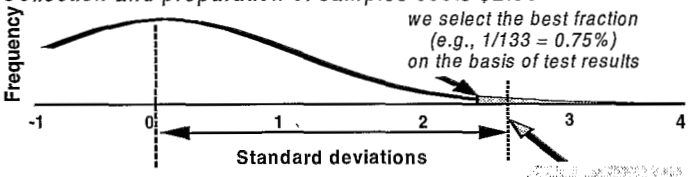
Statistical analysis

Variances. Test error variance was calculated directly from laboratory test results. Sample means were then analysed using PROC GLM of SAS, random model, to give estimates of variance due to genotype and year. These variances were corrected for the genotype-year interaction. This, in turn, was computed from PROC GLM error and test error variance. *Phenotypic variance was genotypic variance + genotype×year variance. Heritability* was the ratio between genotypic and phenotypic variances.

The gain in precision that could be obtained by repeating tests was expressed as *Repeatability (R)*, where R^2= (Phenotypic variance) ÷ (Phenotypic variance + Test error variance). Genotypic correlations were calculated between the Least Squares Means (LSM) of test results for each genotype and the corresponding LSM of voluntary intake, using SAS PROC GLM weighted by (standard error of LSM)$^{-2}$. Selection differentials were taken from published tables (Falconer, 1981). The method for calculating expected percentage gain in voluntary intake per generation is described, with an example, in Fig. 1.

Principles of calculation

Assumptions:
Genotypes are already screened for yield and adaptation
Errors are not correlated
The budget is $1000 per genotype chosen
Collection and preparation of samples costs $2.50



Example (nominal data)

Test: Nylon bag DM loss at 48 h

Cost of 1 test = $5.00, *plus $2.50 for collection*

Number of genotypes tested = $1000 ÷ $7.50 = 133;

Number of genotypes chosen = 1;

therefore, fraction selected = 1/133

Superiority of chosen genotype, *as measured* = 2.61 x †S_{test}
(selection differential, per generation)

Multipliers

Actual phenotypic improvement for test = 2.43 x S_{test} *(per generation)*	x 0.93,	repeatability, ††*R* *(can be improved by repeating test)*
Genotypic improvement for the test = 1.44 x S_{test} *(per generation)*	x 0.59,	heritability, ***h*** *(affected by genotype-environment interactions)*
Genotypic improvement for intake = 0.76 x S_{intake} *(per generation)*	x 0.53,	genotypic correlation between test and intake, ***r***
Percentage genotypic improvement for intake *(per generation)* = 7.5%	x 9.9%	phenotypic coefficient of variation of intake

†*S*: Phenotypic standard deviation (for test or for intake, as shown)
††*R*: Standardized regression coefficient = square root of R^2, where R^2 = variance/(variance + error variance)

Fig. 1. The improvement in straw intake expected in each generation.

Results

Test results were affected more by year than by genotype (Fig. 2). The ability of tests to distinguish genotype, shown as the significance of genotypic variability, was greatest for 48-h *in sacco* DM loss. The significance of genotypic variability of voluntary DM intake was moderate ($P<0.05$), as a result of large Year and Genotype × Year components of variance. *Although grain yield varied genotypically, with a coefficient of variation of around 10%, the statistical significance of this variability was less than for many of the tests for straw.*

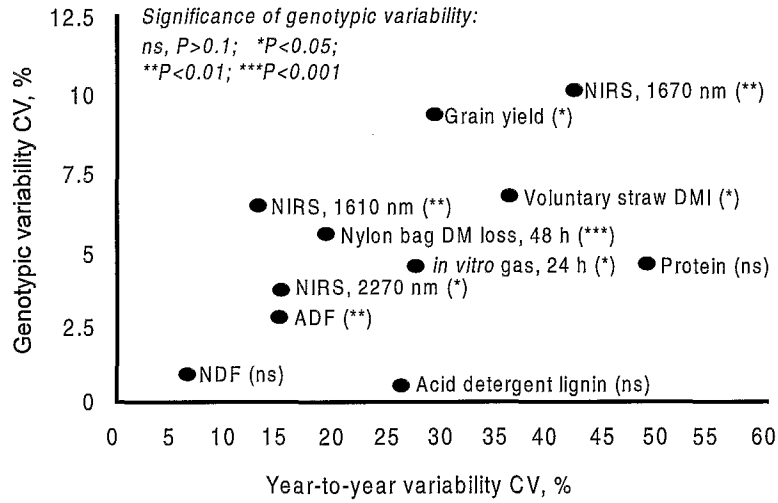


Fig. 2. Effect of genotype and year on barley straw test results and grain yield. Variability expressed as a coefficient of variation (CV). Genotypic variance calculated from genotype and genotype x year interaction mean squares; 44 samples, 8 years.

There was a non-significant positive correlation between grain yield and voluntary straw intake in a set of 32 genotypes of barley in the first 2 years of a recent experiment (Fig. 3).

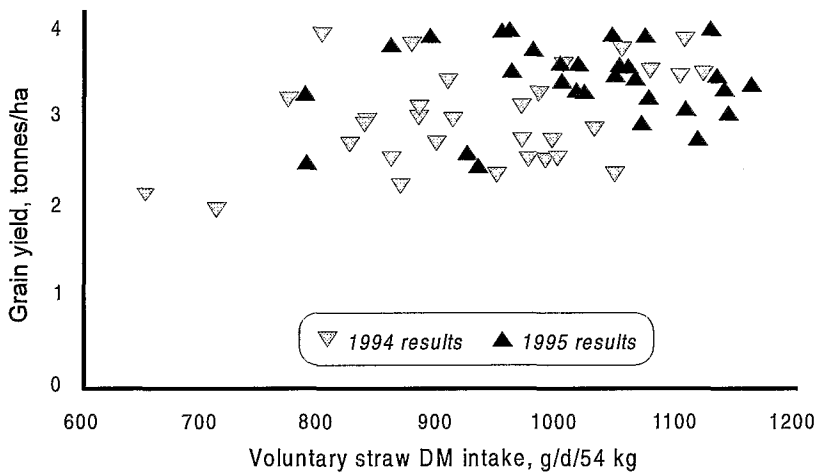


Fig. 3. Relationship between grain yield and straw intake in 32 diverse genotypes. Landraces, modern 2-row, modern 6-row, and crosses amongst these and with wild barley. From an ongoing project on Farmer Participation in Barley Breeding supported by GTZ/BMZ.

Genetic aspects of the best and the worst of the tests described in this paper are illustrated in Table 1. Some of the tests—NDF, crude protein and lignin—were quite unsuitable for genetic evaluation of straw of the 13 barley genotypes. These tests had low heritability, or in other words had high Genotype × Year interactions. The results for lignin were obtained with the acid detergent-72% sulphuric acid method, which measures a different "lignin" from the permanganate or acetyl bromide methods.

Table 1. Genetic progress in the voluntary intake of barley straw expected per generation, given $1000 to select one genotype. Tests listed in descending order of effectiveness

Test name	Number of tests per $1000	Percentage per generation (intake equivalents)			
		Selection differential	Phenotypic progress	Genetic progress	
				For test	In intake
Near Infrared Reflectance Spectroscopy, second derivative (2, 12, 7, 1)					
1662 nm	*270*	*26.7*	*24.9*	*15.0*	*11.5*
1610 nm	270	26.1	22.7	15.1	9.8
2384 nm	270	26.7	25.1	14.2	9.1
2270 nm	270	27.5	26.0	14.5	6.4
Other tests					
Nylon bag (48 h)	133	26.0	24.3	14.4	7.6
Acid detergent fibre	95	24.9	21.7	12.5	7.2
Pair preference	71	23.8	21.3	10.4	6.7
In vitro gas (48 h)	93	24.8	22.1	12.3	6.2
Voluntary intake	*20*	*18.7*	*14.6*	*5.6*	*5.6*
Crude protein	105	25.2	22.5	4.7	1.8
Acid detergent lignin	69	23.7	20.4	0.8	0.5

Discussion

Caution is necessary in interpreting the results of the study. Since voluntary intake is not a perfect indicator of performance there may be a small bias, so that selecting for voluntary intake may perhaps favour more palatable genotypes without regard for their nutritive value. The risk of this is not, however, great, since the r^2 between voluntary intake and body weight change can be as high as 0.85 (Fig. 4).

In the later years of selection, progress may slow down as genetic variability becomes fully exploited. Alternative indicators of nutritive value may be needed. It is always better to use more than one test for each sample. NIRS methods based on more than one wavelength should therefore be developed.

The relationship between grain yield and the nutritive value of straw can be negative where genotypes are affected to various degrees by drought stress (Fig. 5), which reflects experience in Northern Syria. Since barley for dryland farming should be selected under some degree of moisture stress (Ceccarelli, 1993), nutritive value data from such plants are not always ideal for genetic selection. Therefore tests must not be greatly affected by genotype × environment interaction. They must also be well-correlated with animal performance, and be cheap enough to allow a high selection intensity.

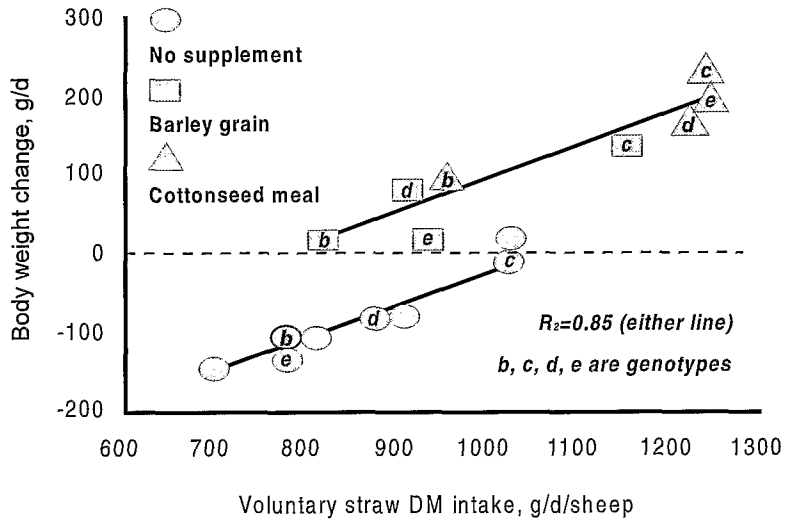


Fig. 4. Illustration of straw dry matter intake as a proxy for weight gain. Four sheep, fed 28 days, offer = 1.2 x intake. Intake is per 54 kg body weight (Source: Capper *et al.*, 1989).

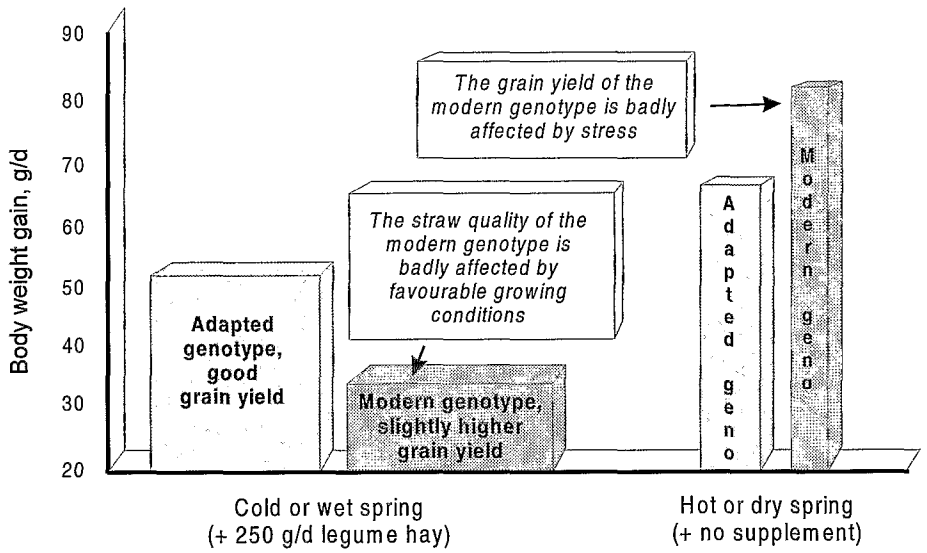


Fig. 5. Illustration of the effect of genotype x environment interaction on the nutritive value of straw and on grain yield. The width of each bar is proportional to grain yield.

Conclusions

Many indirect tests, e.g., selected points on the NIRS spectrum, DM loss from nylon bags, *in vitro* gas production, acid detergent fibre and pair-preference tests were at least as effective as feeding trials for genetically improving the intake of barley straw. This was a result of their lower genotype × year interaction *(leading to higher heritability)* and their lower cost *(leading to a better selection differential)*. Some tests, however, performed badly; tests like crude protein and neutral detergent fibre were too much affected by genotype-year interactions.

It is essential to conduct studies similar to the present one for different sets of germplasm in different agroclimatic zones, and to monitor whether tests have changed in relevance as a result of population

changes in response to using them. In the immediate future we intend to confirm whether the relationships described here occur in all environments, in wheat straw and in other straws.

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