# STRAW STIFFNESS IN LANDRACES OF TWO-ROW BARLEY
## (*HORDEUM VULGARE* L.)

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ABSTRACT

This study was aimed to investigate straw stiffness in land races of two- row barley (*hordeum vulgarel.*). Straw from four landrace populations of barley grown in the Kurdistan Region of Iraq was measured and tested for bending stiffness, showing considerable variation in diameter and in longitudinal bending modulus. In the lower range of diameter, the straw from these landrace populations was highly flexible and was able to lodge without fracture, by curving elastically without fracture or buckling until the head reached the ground. The landrace populations studied contained substantial variation in internode diameter and in the stiffness of the wall material. Selection for internode diameter appeared to have potential for improving lodging resistance. Because lodging potential depends on the weight of the whole shoot as well as on wind forces, it is likely to be increased by pre-harvest moisture content. Decreasing moisture content of the straw and heads reduced the total above-ground weight of the plant by approximately a factor of two during the month prior to harvest.

Keywords: farm-saved seed, biomechanics, genetics, lodging, moisture content

### متانة السيقان في سلالات الشعير ذو الصفين ( *Hordeum vulgare L.*)

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المستخلص

ان الأصناف والسلالات المحلية من الشعير المقاومة للجفاف التي تزرع في المواسم ذات كميات الأمطار التي تتعدى معدلاتها تكون حساسة للاضطجاع نتيجة لزيادة ارتفاع نباتاتها. تم قياس واختبار القش لأربع اصناف من الشعير المزروعة في إقليم كوردستان العراق من حيث صلابة الانحناء في سيقانها وأظهرت النتائج تبايناً كبيراً في القطر وفي معامل الانحناء الطولي، كانت القشة الناتجة عن السلالات المحلية مرنة جداً في النطاق الأدنى من القطر وتمكنت من مقاومة الاضطجاع دون كسر أو انحناء عن طريق الاضطجاع المرن وحتى وصول السنبلة إلى الأرض. تباينت الاصناف المحلية كثيراً في قطر السلاميات وفي صلابة جدران الخلايا، ومن الواضح أن اختيار القطر الداخلي له دور في تحسين المقاومة للاضطجاع لأن إمكانية الإنحناء تعتمد على الوزن الكلي للساق وقوة الرياح ومن المحتمل أن تزداد بزيادة المحتوى الرطوبي قبل الحصاد. تقليل المحتوى الرطوبي في كل من السيقان و السنابل يقلل من الوزن الكلي للأجزاء الهوائية للنبات من خلال هذين العاملين عند شهر قبل الحصاد.

الكلمات المفتاحية *Hordeum sativum*، بذور الفلاح المحفوظة، بايوميكانيك، الوراثة، الاضطجاع، المحتوى الرطوبي

# INTRODUCTION

Barley, as a drought-resistant crop, has a history that goes back to the beginnings of agriculture. In a few parts of the Middle East, farmers still grow landraces of barley, saving their own seed in traditional fashion. Landrace populations represent a living, segregating genetic resource for modern plant breeding as well as a source of resilience against climate change and disruption in war-torn regions (8, 12). While cereal seed banks include landrace material (13), preservation in the field has advantages but the landraces themselves are a fast-disappearing genetic resource (11). Landraces have been used only to a limited extent in experimental agriculture. Obviously, experimentation on landraces is relevant to the farming systems of which they form a part (12), but their variability can also give an indication of the range of variation in specific phenotypic parameters potentially accessible to breeders (14, 15). These advantages are offset by the variability in husbandry and soil conditions from one farmer's field to another, accompanying the genetic variation of interest: a landrace is typically selected by its grower to suit the grower's land (12). A different approach to experimentation is therefore needed, in comparison with genetically uniform cultivars. Modern breeding populations contain barley lines that will survive, and produce a crop of grain, on 200 mm of rain year$^{-1}$, equivalent to full desert conditions (19). Livestock farmers growing barley at the dry limit of cultivation are able to make use of the straw for fodder in years too dry to produce a viable crop of grain: the feeding value of the straw is greater in these circumstances (10). However, a problem arises from the irregularity of rainfall from year to year in localities near the lower limit of average annual rainfall for cereal production. In a year when there is more rain than average, drought-resistant barley lines may grow so tall that they suffer from lodging and the attendant loss of grain production at harvest (20). Lodging in cereals has been reviewed by Berry *et al.,* (4). To prevent lodging, strong straw is a desirable genetic characteristic, but it would seem logical that straw strength should be accompanied by increased lignification (3) or other features of straw composition that would decrease the feeding value of the straw to ruminants (18). There would then be a compromise between feeding value, essential in dry years, and the strength of the straw in the face of lodging problems in years with ample rainfall. In the experiments described here, the dimensions, moisture content and mechanical properties of straw from four landraces of barley grown by Kurdish farmers were measured in the 2007-8 growing season, shortly before the region was disrupted by war and much of its local landrace diversity was lost. This data set, although restricted to a single year, is therefore uniquely valuable. The primary aim of the study was to identify sources of variation, within or between populations, that could be exploited to improve resistance to lodging, if possible without negative effects on feeding value to ruminants. The unusual straw phenotypes present also prompted an examination of variation in moisture content and its relevance to the gravity contribution to lodging.

# MATERIALS AND METHODS

## Sites and landrace populations

Four sites with landrace populations of two-row barley were selected at locations close to the city of Erbil, Kurdistan Region, Iraq (Figure 1) All four sites were within the 320-400 mm mean annual rainfall band, were at the same altitude and had soil textures ranging from silt loam to clay loam. There was no application of irrigation water, fertilizer or pesticides at any of the sites. Otherwise husbandry followed local practice at the farmers' initiative with farm-saved seed, as is normal with landrace barley. There was negligible lodging up to the date of harvest in the growing season 2007-2008.

## Field measurements

Within each of the sites, a farmer's field of 20-30 ha, a 25 m$^2$ study area was randomly selected. At each of four weekly dates before harvest, three replicate 1 m$^2$ sub-plots were harvested for straw and grain yield measurement and 0.5 m$^2$ for determination of dry matter and yield components. Straw and ears were divided for each tiller, weighed and their moisture content (as % of dry matter) was measured after oven-drying overnight. Internode diameter was measured by micrometer.

## Measurement of bending modulus

Three-point bending tests were carried out on a Tinius Olsen H1KS tensile testing machine fitted with a 250N load cell (Tinius Olsen Ltd, 6 Perrywood Business Park, Honeycrock Lane, Salford, Surrey RH1 5DZ, England) and a custom-built jig with variable span and roller bearings 8 mm in diameter contacting the sample. The span varied up to 80 mm depending on the length of the internode being tested. Load-deflection data were captured using the Qmat 5.36 software package and transferred in ASCII format into Excel, where the modulus of elasticity was calculated after selecting the linear region of the load-deflection curve. The culm wall thickness was approximately 16% of the overall diameter, based on measurements of weight and diameter and assuming a mean culm wall density of 0.5 g cm$^{-3}$. The second moment I was calculated as ((outer diameter)$^4$ - (inner diameter)$^4$ / 64. and the bending modulus was calculated as $SL^3/48I$ where S is the slope of the linear part of the load-deflection plot and L is the span of the three-point bending rig (9). Anatomical heterogeneity of the culm walls (6) and ovalisation of the internode cross-section (7) were not considered in the calculation of the material bending modulus. (4, 5)

## RESULTS AND DISCUSSION

### Growing conditions

All four landrace populations were located at sites within the 320-400 mm rainfall band near Erbil. Rainfall during the 2007-2008 growing season was close to the regional average. Detailed weather data for the latter part of the season are shown in Table 1.

**Table 1. Weather conditions during the growing season averaged across five weather stations in a 10 km radius around Erbil, encompassing the four test sites**

| | Mean air temperature, C | Soil temperature, C | Precipitation, mm | Humidity, % | Potential evapo-transpiration, mm |
|---|---|---|---|---|---|
| Jan | 5.5 | 7.5 | 40.7 | 64.1 | 51.9 |
| Feb | 9.5 | 10.4 | 45.1 | 65.4 | 67.0 |
| Mar | 18.4 | 18.7 | 55.1 | 53.7 | 117.1 |
| Aprl | 23.1 | 25.9 | 2.6 | 42.8 | 176.9 |
| May | 25.3 | 32.3 | 1.1 | 39.7 | 303.2 |
| Jun | 31.7 | 39.6 | 0.0 | 33.9 | 386.2 |

## Plant development

The mean rates of development and desiccation of the four landrace barley crops in the 2007 season are shown in Figure 2. Straw growth was completed by approximately mid-April and grain yield reached its maximum by the first week in May, after which growth was arrested by progressive desiccation (terminal drought). Translocation to the grain is considered to cease at about 40% moisture content (1), and the data in Figure 2 are consistent with that. During the month preceding harvest the dry weight of the spike increased by a factor of 2.5, but this increase was almost completely compensated by the decrease in the moisture content of the spike from 110% to near zero. Over the same period the fresh weight of the straw was approximately halved by loss of moisture (Figure 2). These data demonstrate the importance of desiccation in reducing the weight of the plant and thus reducing the gravity contribution to lodging, in addition to the increase in material stiffness that accompanies loss of moisture from the straw (17).

## Internode dimensions at harvest

The straw of the four landrace populations had either three or four internodes per tiller at harvest in 2008: their length and diameter are shown in Table 2.

**Table 2. Internode length and diameter at maturity, at each of the four test sites**

| | Height to base of head, mm | Internode length, mm | | | |
| --- | --- | --- | --- | --- | --- |
| | | Internode 1 | Internode 2 | Internode 3 | Internode 4 |
| Kaniqrzhala | 469 | 83 | 169 | 269 | |
| sd ($n = 10$) | 57 | 41 | 24 | 35 | |
| Sarkarez | 375 | 29 | 83 | 146 | 209 |
| sd ($n = 8$) | 72 | 14 | 29 | 45 | 57 |
| Tworaq | 374 | 52 | 115 | 185 | 254 |
| sd ($n = 13$) | 37 | 26 | 42 | 29 | 39 |
| Grdarasha | 323 | 53 | 116 | 186 | |
| sd ($n = 9$) | 42 | 22 | 27 | 27 | |
| Average | 389 | 56 | 122 | 200 | 242 |
| sd ($n = 40$) | 71 | 33 | 43 | 55 | 56 |

| | | Internode diameter, mm | | | |
| --- | --- | --- | --- | --- | --- |
| | | Internode 1 | Internode 2 | Internode 3 | Internode 4 |
| Kaniqrzhala | | 1.99 | 2.06 | 2.12 | |
| | sd | 0.32 | 0.42 | 0.41 | |
| Sarkarez | | 0.76 | 0.99 | 0.74 | 0.61 |
| | sd | 0.16 | 0.34 | 0.20 | 0.15 |
| Tworaq | | 0.67 | 0.71 | 0.65 | 0.55 |
| | sd | 0.14 | 0.10 | 0.14 | 0.11 |
| Grdarasha | | 0.58 | 0.63 | 0.46 | |
| | sd | 0.11 | 0.09 | 0.13 | |
| Average | | 0.97 | 1.09 | 1.01 | 0.65 |
| | sd | 0.60 | 0.64 | 0.71 | 0.35 |

**Plant height was relatively similar for all four populations, with Kaniqrzhala being the tallest (Tukey LSD 65 mm, P<0.05).**
Internode diameters were relatively small, compared with developed barley varieties, and were highly variable both within and between the populations at the four sites The Kaniqrzhala landrace had internode diameters approximately twice the diameters at the other sites (Tukey LSD 0.15 mm, P<0.05). Straw taper was restricted to the top internode. During the decade following the 2007-2008 season the region was subjected to considerable economic and military disruption, and there was widespread replacement of landraces with commercial varieties. However, at Kaniqrzhala, a small amount of the local landrace was still being grown in 2018 (Figure 3), with mean straw length 379 mm, sd 35 mm; mean 4.7 internodes per stem; and mean internode diameter 2.29 mm, sd 0.44 mm. These straw dimensions were similar to those recorded in the 2008 harvest. Figure 3 shows the unusual manner of lodging, with many stems arching over without fracture. Figure 3 also shows the leaf sheath clasping each internode for most of its length to give a high leaf: stem ratio in the dry matter, a positive factor with respect to feed value.

**Bending stiffness of internode walls**
Figure 4 shows typical load-deflection plots for lower and upper internodes at approximately 10% moisture content. For the lower internodes the curves were slightly convex, probably due to a small amount of ovalisation at higher deflections. The load-deflection plots for the final internodes were linear up to large deflections but with much smaller slope and greater proportionate scatter due to the small diameter. The thickness of the culm walls, calculated on the basis of density $= 0.5$ g/cm$^{-1}$, was relatively constant at about 15-20% of the internode diameter. The mean calculated stiffness of the internode cell-wall material was 10 GPa in the second internode, comparable with softwood material of similar density. Two-way ANOVA showed that in the final internode the mean bending stiffness was less (P < 0.05), about 5 GPa, but variation between plants was large and differences between landrace populations were non-significant (Table-3).

**Table 3. Mean longitudinal bending modulus of the culm wall material from bending tests, GPa**

|  | Internode 2 | Final Internode |
|---|---|---|
| Kaniqrzhala | 12.68 | 4.57 |
| Sarkarez | 6.51 | 2.75 |
| Tworaq | 8.33 | 5.63 |
| Grdarasha | 12.31 | 7.77 |
| mean | 9.96 | 5.18 |
| sd | 3.03 | 2.10 |

Substantial variation in internode diameter and in the bending modulus of the wall material was therefore present in these landraces. Both of these characters would contribute to lodging resistance, but not equally (4, 6). Bending stiffness increases with the fourth power of the diameter, although weight also increases with the square of the diameter if the ratio of wall thickness to diameter is approximately constant. In contrast stiffness increases only linearly with the longitudinal modulus (2). Qualitatively, therefore, it would be expected that increased diameter should be prioritised in selection for lodging resistance. These relationships will be explored in more detail by finite element analysis in a related paper (Jaff and Jarvis, unpublished). The landrace barley populations studied here were an altogether different crop from modern barley cultivars grown in temperate regions. Adapted to low fertility and extreme environments with terminal drought, they were characterised by low grain yield and exceptionally thin and flexible straw, although the thin internodes are not visually evident because of clasping leaves. The thin straw of the landrace barley leads to susceptibility to a kind of lodging that was present in the 2018 season at Kaniqrzhala but, to the best of our knowledge, has not been modelled in temperate barley crops. Rather than breaking or buckling, the straw bends elastically until the weight of the head prevents recovery to a vertical position.

Bending is accompanied by some root displacement, so that this form of lodging might be classified as root lodging, but the final bending angle of the straw is much greater than the displacement angle of the root system. Some degree of secondary buckling (that is, crimping or folding (16) of the straw occurs at the points of stress concentration where one stem falls across another. Further secondary buckling is hard to avoid when walking through a lodged crop to assess it, but the primary event appears to be elastic bending without mechanical failure.

1- Landrace barley populations from Kurdistan had straw with very thin internodes, which made these landraces susceptible to an unusual form of lodging in which the straw bends over under the weight of the head, without any kind of fracture

2- The four populations studied showed approximately twofold variation in stiffness, due to twofold variation in straw diameter and in the bending modulus of the culm wall material.

3- Internode diameter appeared to be the most promising variable for improvement of lodging resistance without loss of feeding value.

4- The decreasing moisture content of both the head and the straw, approaching the harvest date, more than compensated for the increasing dry weight of the head during grain filling
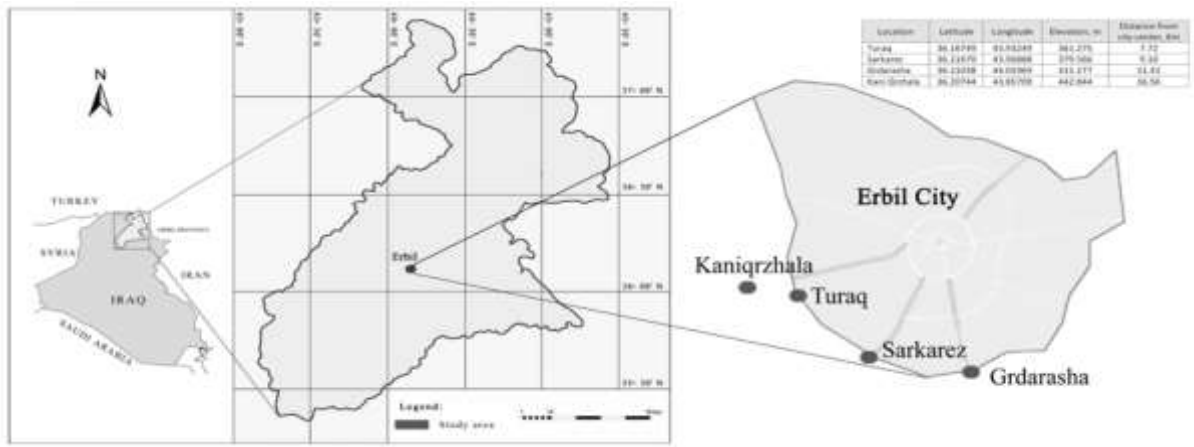
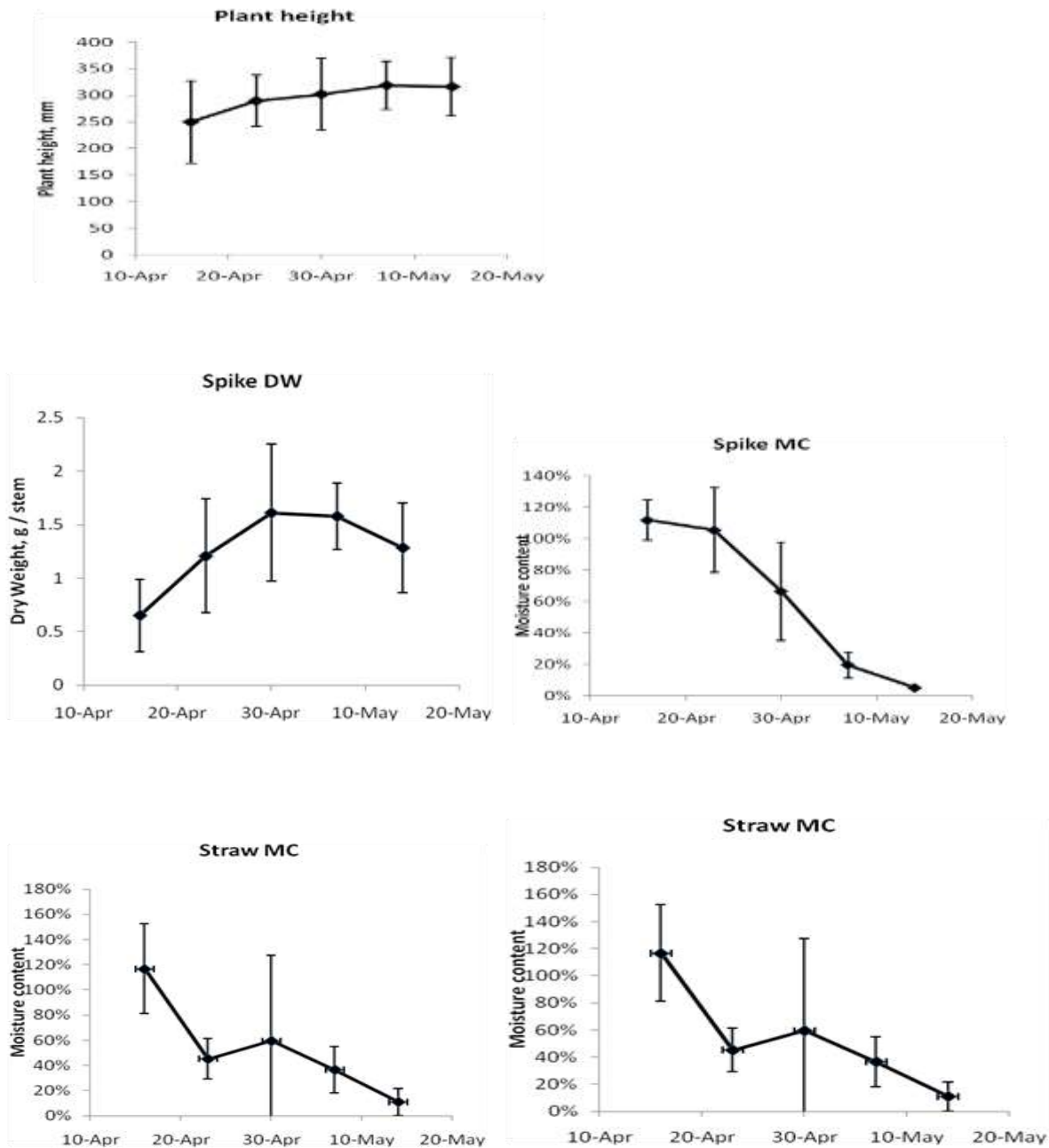**Fig. 1. Location of the four study sites**



**Fig. 2. Mean rate of development, dry weight increment and moisture content of the four landrace barley crops in the 2008 season. Average of all four sites. Error bars show standard deviation (*n* = 40).**

**Fig. 3. The Kaniqrzhala landrace, surviving in the same farmer's field in 2018. Note the tendency to lodging by bending of the straw, without fracture except where one tiller crosses another**
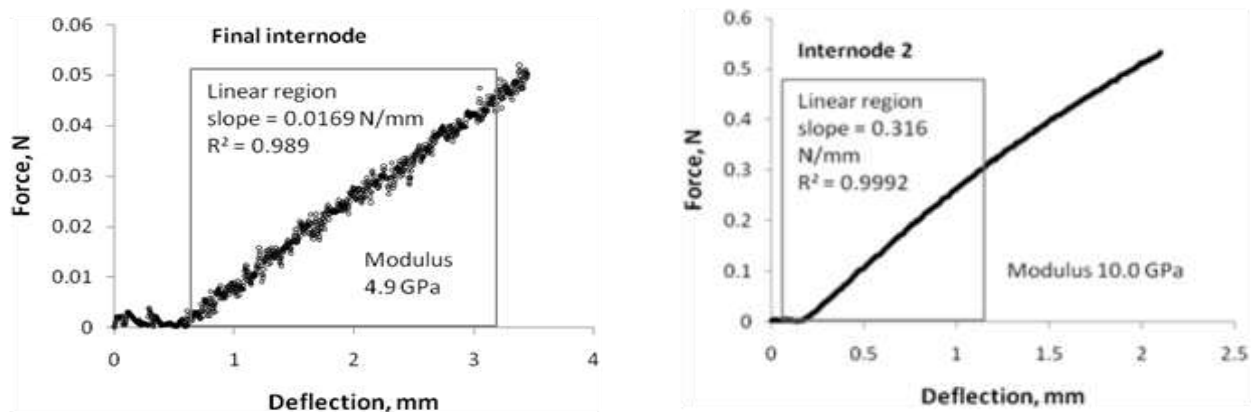


**Fig. 4. Typical load-deflection plots in three-point bending tests of internode 2 and the apical internode. Note the different vertical scales, due to the smaller diameter of the apical internodes.**

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