Kernel weight distribution within oat (*Avena sativa* L.) panicles

M.W. Crampton, D.J. Moot and R.J. Martin[1]

Soil, Plant and Ecological Sciences Division, PO Box 84, Lincoln University, Canterbury, New Zealand
[1] New Zealand Institute for Crop & Food Research Ltd., Private Bag 4704, Christchurch, New Zealand

Abstract

Variability in kernel size of oats (*Avena sativa* L.) for processing necessitates grading into streams for hulling, followed by re-mixing for product manufacture. This study investigated sources of kernel size variation within oat panicles. Crops of the milling oat cv. Drummond, sown on 16 September 1994 and 16 May, 1995 at Crop & Food Ltd, Lincoln, New Zealand, were analysed for systematic variation in panicle structure and kernel weight within the panicle. The grain yield per panicle was higher ($P<0.05$) from the autumn (2415 mg) than the spring (1358 mg) sown crops. This difference was related to 80% more ($P<0.05$) kernels per panicle in the autumn sown crop. Nodes per panicle and branches per node were consistently, but not significantly higher, with the increased number of kernels due to 110% ($p<0.05$) more spikelets per branch. Each spikelet produced a primary and secondary floret, but not all florets developed into a kernel. The number of kernels per spikelet was 30% lower ($P<0.05$) in the autumn sown crop, with 40% of potential florets aborted. The primary:secondary weight ratios were 1.80 and 2.13 for the spring and autumn crops, respectively. This reflected the bimodal kernel weight distributions in both crops, with coefficients of variation of about 22%. For both sowing dates the primary kernels produced about 66% of the panicle, and therefore, crop yields. Spikelet position within the panicle and anthesis date had no effect on kernel weight. Thus, a uniform, monomodal distribution, desired for processing, would only result by altering relative kernel weights or removing secondary florets from the panicle.

Introduction

In New Zealand about 115,000 tonnes of oats (*Avena sativa* L.) are produced annually (Pyke, 1996), with 70% used for stock feed, 25% for human consumption and 5% for seed (Dunbier and Bezar, 1996). Approximately 90% of the oats are produced in the South Island, with the majority for human consumption grown in Southland (Dunbier and Bezar, 1996). The association of β-D-Glucans, found in high levels in oats, with reduced blood cholesterol levels has renewed demand for processed oats (Welch, 1995).

Efficient processing of oats is important to maintain the viability of the New Zealand industry. After cleaning and grading, oats require hulling to remove the lemma and palea which are firmly attached to the caryopsis (White, 1995), to produce groats. Ganβmann and Vorwerck (1995) described this as a precise mechanical process that required kernels with uniform weight. However, variability in kernel size within oat crops necessitates grading into streams, and thus inefficient double handling, before hulling. Variability in kernels is also undesirable in other areas of processing, for example, rolling (Ganβmann and Vorwerck, 1995).

Kren *et al.* (1992) highlighted variation in kernel size as a problem in oat crops with small grains lost as screenings, representing a yield loss to producers, and non-uniform larger grain sizes complicating processing. Kernel size has a direct relationship with kernel weight and therefore kernel weight was the measured variable in this study.

The aims were to identify and quantify any patterns of kernel weight variation within panicles from spring and autumn sown crops of the milling oat cv. Drummond. Once identified, this may indicate causes of variability in kernel size found in oats, and enable subsequent physiologically based studies to determine whether variability can be reduced.

Materials and Methods

Experimental details

The experiment was sown as a randomized complete block design on two dates, 16 September 1994 and 16 May 1995. The earlier sowing was harvested on 8 February 1995, after a 146 day growing season, compared with 274 days for the later sowing. The oat cultivar Drummond, a semi-dwarf, late-maturing milling oat, was precision sown with an Øyjord cone drill at 167 kg/ha resulting in a population of about 290 plants per square metre for both sowing dates. Plots were 15 x 2.7 m. The experiment was located at Crop & Food Research's Lincoln farm, on a Templeton silt loam soil. Crop management aimed to maximise crop production although irrigation of crops was applied close to wilting point due to limitations of the irrigation system. No fertiliser was applied to minimize the risk of lodging which would hinder the retrieval of kernels. Herbicide (chlorsulfuron, 15 g a.i./ha), insecticide (pirimicarb, 125 g a.i./ha) and fungicide (tridimenol, 125 g a.i./ha) were applied as required. Nets covered the crops after anthesis to prevent bird damage. Further experimental details were given by Martin (1996).

Measurements

At maturity, defined as when kernels had dried and become hard, main stem panicles were randomly selected from six plants in each plot. The structural parts of each panicle (nodes, branches, spikelets and kernels) were identified. Nodes were numbered basipetally in ascending order, starting with the apical node as node one, following the development of the panicle (White, 1995). Branches at each node were numbered in ascending order in relation to increasing distance of the first spikelet to the central rachis. Spikelet position along each branch was also identified by increasing distance from the central rachis. Primary and secondary kernels were identified as being from floret one or two within each spikelet. Each kernel was removed and dried for 24 hours at 80°C in a forced air oven to constant weight to determine kernel weight.

Statistical analysis

Differences in panicle structure (node per panicle, branches per node, spikelets per branch and kernels per spikelet) among replicates and between sowing dates were assessed using analysis of variance (ANOVA). Differences in kernel weight, kernel number and grain yield among nodes within a panicles were analysed separately for each kernel class (primary and secondary) at each sowing date. Means separation was based on least significant difference tests. Students t-tests were used to compare mean values per node between sowing dates. The frequency distribution of primary and secondary kernel weights was tested for normality using the Shapiro-Wilks (Minitab, 1989) test for each sowing date.

Results

Panicle structure

Kernel number per panicle in the autumn sown crop was 80% higher than the spring crops due to a 110% increase ($P < 0.05$) in the number of spikelets per branch. Nodes per panicle and branches per node did not differ significantly between the crops (Table 1). Each spikelet produced a primary and a secondary floret, but the number of kernels which developed from these florets was 30% lower ($P < 0.05$) for the autumn than the spring sown crop.

Within panicles, kernel number differed ($P < 0.05$) among nodes. A single spikelet with a primary and a secondary kernel was produced by the apical and second nodes. However, the number of kernels increased down the panicle with the highest number of branches, spikelets and kernels at the third from bottom node for both sowing dates (Table 2). The maximum number of kernels per node was 21 from the autumn sowing compared with 10 from the spring sown crop. The lower ($P < 0.05$) number of kernels per spikelet in the autumn sown crop (Table 1) resulted in single kerneled spikelets which were formed mainly from the lower, multi-branched nodes (6, 7 and 8).

Kernel weight

The primary:secondary kernel weight ratio over all nodes was 1.80 for the spring sown crop and 2.13 for the

Table 1. Panicle structure of oat crops for two sowing dates at Lincoln.

Sowing date	Nodes per panicle	Branches per node	Spikelets per branch	Kernels per spikelet	Kernels per panicle
16 Sep 94	7.8	3.4	0.9	1.7	41.6
16 May 95	8.3	4.1	1.9	1.2	76.7
p	0.21	0.08	0.002	0.02	0.03
SEM	0.25	0.14	0.14	0.11	0.34

Table 2. Oat kernel weight, kernel number and grain yield from two sowing dates at Lincoln. Means within columns for each sowing followed by the same letter were not significantly different at P<0.05.

	Mean kernel weight (mg)		Mean kernel number per node		Grain yield per node (mg)	
Node	Primary	Secondary	Primary	Secondary	Primary	Secondary
16 September 1994						
1	43.0 ab	26.1 a	1.0 d	1.0 b	41.1 c	24.6 b
2	45.4 a	24.5 a	1.0 d	1.0 b	45.4 c	24.5 b
3	44.2 ab	24.3 a	3.8 c	3.8 a	163.9 b	87.0 a
4	44.2 ab	26.5 a	1.0 d	1.0 b	38.6 c	23.0 b
5	42.2 ab	24.5 a	4.1 bc	3.9 a	172.5 b	95.9 a
6	41.3 abc	23.4 ab	5.3 a	4.7 a	212.5 a	108.2 a
7	39.8 bc	23.0 ab	4.5 bc	3.8 a	183.6 ab	87.6 a
8	37.7 c	19.3 b	1.0 d	1.0 b	33.0 c	16.2 b
Mean (per node)	42.2	23.4	2.7	2.5	111.3	58.4
Total (per panicle)			21.6	20	890.6	467.0
SEM	1.50	1.58	0.18	0.31	13.30	9.05
16 May 1995						
1	39.6 a	17.4 a	1.0 e	1.0 f	29.4 f	13.9 e
2	43.0 a	17.8 a	1.0 e	1.0 f	37.7 f	12.6 e
3	40.3 a	20.7 a	1.6 de	1.3 f	66.5 ef	25.5 de
4	38.9 a	18.9 a	3.0 d	2.9 e	117.2 e	56.1 d
5	41.6 a	21.5 a	4.8 c	4.6 d	201.3 d	97.0 c
6	38.5 a	21.0 a	7.7 b	6.1 c	297.2 c	128.2 c
7	42.5 a	21.8 a	11.4 a	10.0 a	483.0 a	219.0 a
8	40.6 a	20.6 a	10.7 a	8.6 b	436.1 b	178.7 b
9	34.9 b	10.0 b	0.3 e	0.3 f	11.9 f	3.5 e
Mean (per node)	40.0	18.8	4.5	4.0	186.7	81.6
Total (per panicle)	-	-	40.9	35.8	1680.3	734.5
SEM	1.81	1.54	0.49	0.38	18.97	10.49

autumn sown crop. The kernel weight distributions show the difference ($P < 0.05$) between primary and secondary weights for both sowings. For the spring sown crop, the mean primary kernel weight was 42.2 mg with a standard deviation (SD) of 4.8. In contrast, the mean secondary kernel weight was 23.4 mg with a SD of 5.0 (Fig. 1). Together, these produced a bimodal distribution ($P < 0.05$) of kernel weights, ranging from 1 to 60 mg and a coefficient of variation (CV) of 19%. The distribution from the autumn sown crop was similar, with a primary kernel weight of 40.0 mg but lower ($P < 0.05$) secondary kernel weight of 18.8 mg and a CV of 24%. Analysis of the primary and secondary kernel weight distributions separately for each sowing date showed each distribution was left skewed, with a CV of 7% for primary kernels and 14% for secondary kernels.

There was a maximum CV of 16% for the primary and 8% for the secondary kernels within each node. The lowest kernel weights were produced at the bottom node. However, there was no significant variation in kernel weights among the other nodes (Table 2).

Grain yield per panicle

The primary kernels produced about 66% of the total panicle yield in the spring sown crop and 70% in the autumn sown crop. Therefore, the majority of the total

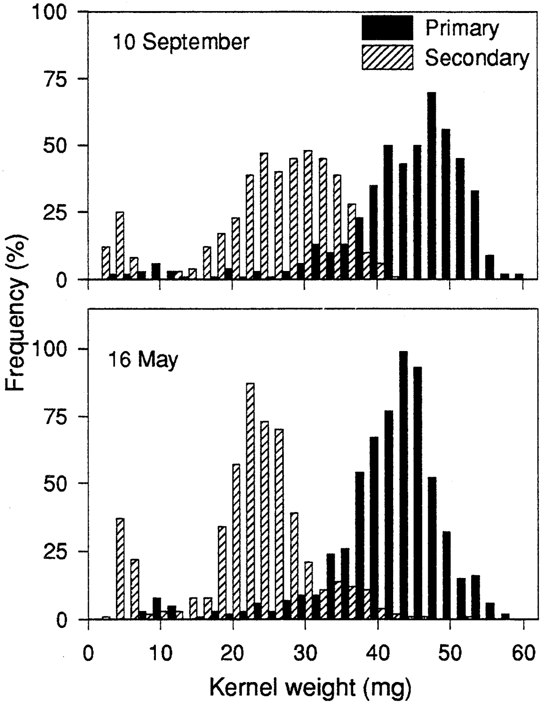

Figure 1. Kernel weight distributions of primary and secondary grains for oat cv. Drummond sown on 16 September 1954 and 16 May 1995 at Lincoln.

crop yield was due to the primary kernels. The grain yield was 44% lower (P < 0.05) in the spring sown crop than the autumn sown crop.

The difference (P < 0.05) in grain yield among nodes corresponded to changes in kernel number and not kernel weight (Table 2). Thus, 63% of the grain yield originated from the bottom three nodes above the lowest node in the spring sown crop and 72% in the autumn sown crop. The 78% higher (P < 0.05) yield per panicle from the autumn sown crop also resulted from an increased number of kernels and not a change in kernel weight.

Discussion

This study showed that kernel position within an oat panicle (node, branch or spikelet position) did not influence kernel weight. The main source of variation in kernel weight was floret position within the spikelet.

Kernels produced from the primary floret were about twice as heavy as those from the secondary floret, regardless of sowing date. This resulted in two distinct kernel weight classes and thus a bimodal frequency distribution of kernel weights from each crop. This contrasts with other cereals which generally produce a mono-modal distribution of kernel weights (Bremner and Rawson, 1978; Hay and Walker, 1994) with systematic variation caused by spikelet position within the spike (Scott and Langer, 1977).

It is the bimodal distribution and large range of kernel weights (CV = 22%) within oat crops that necessitates grading and hence double handling of kernels before processing. Separately, the kernel weight distributions from primary and secondary florets had low CV (< 16%), similar to that found in other cereals (Hay and Walker, 1994). The two weight classes probably form the basis of the size classes used by processors for grading before hulling. To eliminate the need for grading, a mono-modal distribution with a low CV is required. Ideally, the primary:secondary kernel weight ratio would be close to 1.0 rather than the 2.0 found in this study or the 1.5 reported by Tibelius and Klinck (1985).

Kren *et al.* (1992) suggested variability in oat kernel weights may result from differences in anthesis dates. However, this was not observed either within panicles or between autumn and spring sown crops. Within panicles, anthesis develops basipetally with the apical spikelet reaching anthesis first, followed seven to ten days later by spikelets at the lowest node (Bonnett, 1961). In this study the kernels from the apical spikelet were similar in weight to those from heavily branched lower nodes (Table 2). Altering the time to anthesis also had no effect on the distribution of kernel weights. Both the spring and autumn sown crops produced bimodal distributions despite the 128 day longer duration for growth of the autumn crop. As expected (Gallagher and Biscoe, 1978), longer crop duration did increase the kernel yield per panicle from 1358 mg for spring sowing to 2415 mg for the autumn sowing. The yield increase resulted from the increased number of kernels due to increases in the number of spikelets per branch but was slightly offset by a reduced number of kernels per spikelet (Table 1). Despite the large difference in the number of kernels per panicle, the constancy of the bimodal kernel weight distribution indicated sowing date could not be used to reduce variability or produce a more uniform mono-modal distribution.

The difference in mean kernel weight between autumn and spring sown crops of the same cultivar does indicate some plasticity in kernel weight. Thus, future research should be physiologically based to determine whether kernels from primary or secondary florets can be manipulated to produce a uniform mono-modal distribution, with a kernel weight ratio close to 1.0. If successful, agronomic practices may produce the same result. Alternatively, uniformity in kernel weight distributions may come from increasing primary floret numbers per panicle and/or eliminating secondary florets via cultivar selection.

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