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Supporting UK malting barley with improved market intelligence on grain skinning

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CONTENTS

1. Abstract

Spring barley grain destined for malting and downstream processes e.g. brewing and distilling must meet set quality requirements, including physical integrity, in order to optimise processing efficiency. If a batch of barley grain fails to meet malting specification, it may be rejected at intake. Intact barley grains have an adherent outer coat, or husk, enclosing the main body of the grain (the caryopsis). Good adhesion between the husk and the caryopsis is an essential grain quality requirement for the malting industry. Detachment, or loss, of the husk is an undesirable condition known as "grain skinning"; it causes significant handling and processing problems for maltsters, brewers and distillers, leading to inefficient processing and large financial costs. We report on wide variation in skinning susceptibility (from moderate to high) among barley varieties that had recently entered National List or Recommended List trials. Whilst evidence for genotypic variation in skinning is encouraging for future crop breeding and variety selection, our work confirmed that most current malting barley varieties are highly susceptible to skinning. The effects of agronomic inputs on grain skinning were considerably smaller than those associated with variety, growing season or crop handling (combine harvester settings). Fungicide treatments had no significant effect on skinning; this included crops grown with or without fungicide. Likewise, plant growth regulator had no significant effect on skinning. Effects of nitrogen fertiliser on skinning were small, but inconclusive. Skinning increased significantly in crops that were harvested late compared to those harvested early. This supports our view that crops with a later, or prolonged, ripening phase are at increased risk of skinning. Combine harvester settings had a significant effect on skinning; with increased drum speed and/or a reduced area for grain flow (tightening the concave) significantly increasing husk loss. There was no evidence for agronomic influences on grain size (weight) or specific weight being associated with differences in skinning. However, in some seasons, and under some growing conditions e.g. late sown crops, reduction in grain size and specific weight coincided with an increase in screenings and skinning. We conclude that variety choice, pre-harvest weather conditions and crop handling (combining) have significant influence on skinning, whilst routine agronomy has little or no effect.

2. Introduction

Intact barley grains have an adherent outer coat, or husk, enclosing the main body of the grain (the caryopsis). Detachment or loss of the husk, also known as grain skinning, is one of the most serious grain quality problems affecting malting barley as it causes inefficiencies during malting, and downstream in brewing and distilling. Grain bulks can be rejected at intake if levels of skinning levels are too high. Barley grains without husks will uptake water and germinate more rapidly than those with firmly adhering husks. This means that skinned grain in a batch of malting barley results in uneven malting through over- or under-modification of starch (Roumeliotis et al.1999; Agu et al. 2002; Agu et al. 2008; Bryce et al. 2010). The intact husk also protects the embryo from mechanical damage during harvest and post-harvest handling. Grains without husks are more likely to sustain physical damage which may harm the embryo and delay, or even prevent, germination (Roumeliotis et al. 2001; Agu et al. 2002; Olkku et al. 2005). Recent reports from the malting industry, and data from AHDB crop trials, suggest that new spring barley varieties are becoming increasingly susceptible to skinning. There were widespread reports of grain skinning in spring barley crops from harvests 2012 and 2015, with the popular varieties Concerto and Propino being badly affected in both Scotland and England.

Significant varietal (genetic) influences on grain skinning have been identified by SRUC and the James Hutton Institute (JHI), as part of the BBSRC Crop Improvement Research Club (CIRC) project on ‘Causes and control of grain skinning in malting barley: phenotyping and genetic analysis’ (BB/J019623/1). Our research has characterised varieties with low, moderate or high susceptibility to skinning (Brennan et al. 2017a). A major concern among farmers and the malting sector is the apparent lack of choice in ‘robust’ malting barley varieties, including those with good resistance to skinning. Currently, only seven spring barley varieties have Full Approval for brewing or distilling from the Malting Barley Committee. Of these, the variety Concerto accounted for half of the UK intake and more than 70% of the Scottish intake in 2017. Evidence from commercial intakes and crop trials highlight that the varieties Concerto and Propino have high risk of grain skinning. By contrast, the older variety Optic has low to moderate risk. Limited data has indicated that other recently introduced varieties have moderate or high susceptibility to skinning. Of more concern is that several provisionally recommended varieties on AHDB cereals list have shown considerable weakness to skinning (SRUC and Scottish Agronomy data). Variety or genetic variation in skinning as described by Brennan et al. (2017a) is just one influencing factor on the condition. There are also strong environmental (Aidun et al. 1990; Psota et al. 2011) and crop handling (Olkku et al. 2005) influences on skinning. Anecdotal evidence from industry implicates extended grain-fill periods, particularly with prolonged wet weather (as in 2012) or intermittent and dry weather (as in Scotland in 2015) in increasing skinning risk.

Following discussion with AHDB, growers, maltsters and NFU Scotland, we highlighted an industry priority to understand how crop management and handling might influence grain skinning, and if appropriate to support the barley sector with practical remedial advice. Although a large amount of information on skinning and other grain characteristics is collected at intake each year by the malting industry, and as part of official variety testing in National and Recommended List trials, we don't know the extent to which crop management contributes to variation in skinning. In particular, growers have asked if their routine agronomy, including the use of fungicides, plant growth regulator and nitrogen fertiliser, has any effect on husk loosening or loss. Initial work at SRUC indicates that grain handling including combining, threshing and cleaning increase husk loosening, but this needs to be investigated further.

In this study, our approach was to establish a series of variety and agronomy trials at SRUC and Scottish Agronomy Ltd. to investigate the effects of crop management, including crop protection inputs and combine harvester settings, on grain skinning. This was supported by assessment of grain samples from NL and RL trials and commercial malting intakes. This approach would help to identify skinning risk in new varieties and support ongoing research on genetic susceptibility or resistance among varieties (e.g. Brennan et al., 2017a). SRUC and Scottish Agronomy undertook assessment of grain skinning using a standardised protocol developed by SRUC in partnership with the Malting Barley Committee and its Micro-Malting Group. The work programme had three main objectives:

(1) To gather industry knowledge on the extent of grain skinning in spring barley.
(2) To evaluate grain samples from: (a) AHDB funded agronomy trials, (b) commercial barley intakes, (c) official RL and NL variety trials and (d) a variety screen in conjunction with the BBSRC CIRC grain skinning project.
(3) To develop methods to screen for susceptible and resistant varieties; including the influence of agronomic factors on grain skinning.

These objectives would deliver the following outputs:
(1) An evaluation of variety risk for grain skinning.
(2) An understanding of how growing conditions (seasonal variation) affect grain skinning.
(3) Guidelines on how agronomy influences grain skinning.
(4) Protocols for field screening and assessing skinning in variety trials.

3. Materials and methods

3.1. Industry (commercial) samples

Our knowledge of how grain skinning varies across regions and seasons was supported through consultation with the malting sector, including collation of grain skinning data from malting intakes i.e. barley samples about to enter processing. SRUC consulted with the Malting Barley Committee and its Micro-Malting Group about further development of a grain skinning scoring protocol for use in variety testing; the latest version of the SRUC and MMG protocol is described in section 3.4 and in Appendix 1. A malting company provided samples from the 2012 and 2013 crops for SRUC to evaluate. These samples were supplemented by bulked samples from an SRUC agronomy site in Midlothian, in 2015.

3.2. Variety trials

3.2.1. Recommended List and National List trials

Grain samples from official AHDB RL and BSPB NL funded spring barley variety trials in Aberdeenshire and Perthshire were sourced from harvest 2015 and scored for grain skinning using the SRUC-MMG protocol (section 3.4 and Appendix 1).

3.2.2. SRUC and Loirston Charitable Trust funded trials

Additional grain samples were sourced from SRUC spring barley variety trials sown in Aberdeenshire at two sowing dates from harvests 2012 and 2013, funded by the Loirston Charitable Trust.

3.2.3. BBSRC Crop Research Improvement Club (CIRC) trial 2013

An objective of this project was to support the BBSRC CIRC grain skinning project by phenotyping a trial of one hundred varieties grown at the Bush Estate in 2013. This trial was sown as a single replicate of mini-plots (6 rows wide and 1 m length), with seed sourced from the Association Genetics of Elite UK Barley (AGOUEB) collection maintained at the James Hutton Institute. At harvest, plots were sampled by hand, threshed using a Wintersteiger grain thresher and scored for grain skinning using the SRUC MMG protocol.

3.3. Agronomy trials for screening of grain skinning

In designing our spring barley agronomy trials, we considered how variety choice and a range of crop protection inputs might influence skinning. This would enable us to advise farmers on aspects of routine crop management that might modify skinning risk, but also develop protocols for field screening of grain skinning e.g. in variety trials. Our work included a series of combine harvester settings trials, in which adjustments were made to drum speed and concave tightness.

Scottish Agronomy undertook trials at two sites, and SRUC at one site, in 2014 and 2015. The treatments were combinations of nitrogen fertiliser x fungicide x plant growth regulator x variety as outlined in Tables 1 and 2. The Scottish Agronomy trials at Glenrothes, Fife, and Ellon, Aberdeenshire, compared two fungicide programmes based on Proline and Siltra, with and without the plant growth regulator (PGR) Moddus, at two levels of nitrogen fertiliser (130 kg N/ha and 170 kg N/ha). The trials at Glenrothes and Ellon had a factorial design, with two replicate blocks. The SRUC trial at the Bush Estate in Midlothian compared a fungicide-treated and untreated programme, with and without a PGR (Moddus), at two levels of nitrogen fertiliser (120 kg N/ha and 170 kg N/ha). The Midlothian trial design was a split-plot with nitrogen fertiliser as the whole plot, with two replicate blocks. Both the Scottish Agronomy and SRUC trials included three varieties, Optic, Concerto and Propino. Plots were harvested using plot combines, with samples retained for assessment of grain skinning. A combine settings trial at SRUC's Midlothian site was undertaken in in 2014, 2015 and 2016, in which replicate plots of two varieties were harvested at five settings for both combine drum speed (from 800 to 1600 rpm) and concave tightness. In 2014, the varieties were Quench and Sanette, whilst in 2015 and 2016 the varieties were Propino and Westminster. In all trials, yield, grain quality and grain skinning data were collated for statistical analysis using Genstat 16th Edition (see 3.5).

3.4. Grain skinning assessment

We used the current SRUC MMG protocol [version 4] to assess grain skinning as described by Brennan et al. (2017a). The procedure used subsamples of 100 grains. Individual grains with 20% or greater husk detachment or loss by area were recorded as "skinned" and grains with less than 20% husk loss by area were "intact". Skinning could occur across any part of the grain ranging from a few percent of the husk lost to complete husk detachment. Small grains (or screenings) were excluded from the 100 grain subsample or by screening the bulk over a 2.2 mm or 2.5 mm slotted sieve. The procedure was repeated for a minimum of three replicate sub-samples of 100 grains and the mean calculated. This provides the percentage of skinned grain from each the bulk, or grain sample. Depending on the severity of skinning, other characteristics of the sample are made as follows:

(1) tendency for samples to include loss of the palea (ventral side)

(2) loss of the lemma (dorsal side)

(3) husk loss at the proximal or distal (awn) end of grains

(4) number of grains that are 100% skinned

Table 1. Treatments used in Scottish Agronomy Ltd agronomy trials at Glenrothes, Fife and Ellon, Aberdeenshire in 2014 and 2015.

Treatment	Varieties	Nitrogen		Fungicide		PGR (Moddus)
		Seed bed	GS12-13	GS26-30	GS39-49	GS26-30
1	Concerto, Optic and Propino	65 kg N	65 kg N	Proline 0.3 l Bravo 1.0 l	Proline 0.3 l Bravo 1.0 l	No
2	Concerto, Optic and Propino	65 kg N	65 kg N	Proline 0.3 l Bravo 1.0 l Moddus 0.15 l	Proline 0.3 l Bravo 1.0 l	Yes
3	Concerto, Optic and Propino	65 kg N	65 kg N	Siltra 0.4 l Bravo 1.0 l	Siltra 0.4 l Bravo 1.0 l	No
4	Concerto, Optic and Propino	65 kg N	65 kg N	Siltra 0.4 l Bravo 1.0 l Moddus 0.15 l	Siltra 0.4 l Bravo 1.0 l	Yes
5	Concerto, Optic and Propino	85 kg N	85 kg N	Proline 0.3 l Bravo 1.0 l	Proline 0.3 l Bravo 1.0 l	No
6	Concerto, Optic and Propino	85 kg N	85 kg N	Proline 0.3 l Bravo 1.0 l Moddus 0.15 l	Proline 0.3 l Bravo 1.0 l	Yes
7	Concerto, Optic and Propino	85 kg N	85 kg N	Siltra 0.4 l Bravo 1.0 l	Siltra 0.4 l Bravo 1.0 l	No
8	Concerto, Optic and Propino	85 kg N	85 kg N	Siltra 0.4 l Bravo 1.0 l Moddus 0.15	Siltra 0.4 l Bravo 1.0 l	Yes

Table 2. Treatments used in SRUC agronomy trials at Bush Estate, Midlothian in 2014 and 2015.

Treatment	Varieties	Nitrogen		Fungicide		PGR (Moddus)
		Seed bed	GS12-13	GS24-30	GS49	GS24-30
1	Concerto, Optic and Propino	60 kg N	60 kg N	0.5 l Siltra Xpro 0.15 l Vagus 1.0 l Bravo	0.5 l Siltra Xpro 1.0 l Bravo	No
2	Concerto, Optic and Propino	60 kg N	60 kg N	0.5 l Siltra Xpro 0.15 l Vagus 1.0 l Bravo 0.15 l Moddus	0.5 l Siltra Xpro 1.0 l Bravo	Yes
3	Concerto, Optic and Propino	60 kg N	60 kg N	None	None	No
4	Concerto, Optic and Propino	60 kg N	60 kg N	None 0.15 l Moddus	None	Yes
5	Concerto, Optic and Propino	85 kg N	85 kg N	0.5 l Siltra Xpro 0.15 l Vagus 1.0 l Bravo	0.5 l Siltra Xpro 1.0 l Bravo	No
6	Concerto, Optic and Propino	85 kg N	85 kg N	0.5 l Siltra Xpro 0.15 l Vagus 1.0 l Bravo 0.15 l Moddus	0.5 l Siltra Xpro 1.0 l Bravo	Yes
7	Concerto, Optic and Propino	85 kg N	85 kg N	None	None	No
8	Concerto, Optic and Propino	85 kg N	85 kg N	None 0.15 l Moddus	None	Yes

3.5. Data analysis

Statistical analysis was carried out by analysis of variance (ANOVA) as a factorial or split-plot design using Genstat (16th Edition). The ANOVA partitioned variation into main effects and two-way interactions. For agronomy and combine setting experiments that were replicated over two years, the year factor was considered as a random effect. Likewise, agronomy trials replicated over years and sites included these factors as random effects. Prior to statistical analysis, grain skinning data (scores based on counts of 100 grains and expressed as percentages) were transformed using the arcsine function to improve normality of data distribution and increase homogeneity of the variance. Other crop yield and grain quality data including thousand grain weight (TGW) and specific weight were not transformed. Tables and figures present grain skinning as percentages. Comparison of grain skinning means for agronomic treatment or variety was made using Duncan's multiple comparison on arcsine transformed data.

4. Results

4.1. Industry (commercial) samples

Variation in skinning among varieties from commercial intakes in 2012 (Fig. 1) and 2013 (Fig. 2), and from SRUC experimental plots in 2014 (Fig. 3) demonstrate strong seasonal and variety effects.

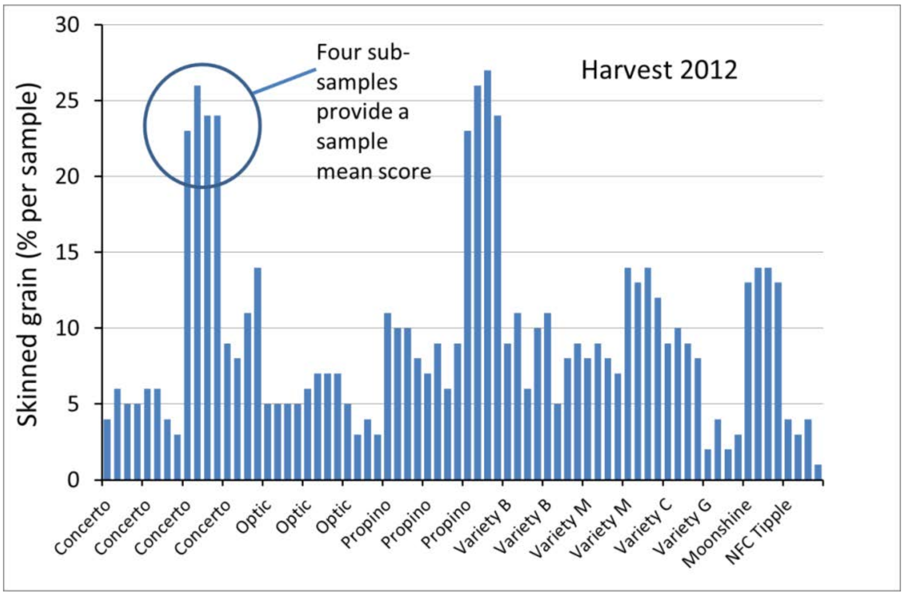


Fig. 1. Variation in percent of skinned grain in sub-samples from a commercial malting intake from central-east Scotland in 2012. Each bar is the score from a sub-sample of 100 grains. A mean for each intake sample is derived from the mean of the four sub-samples.

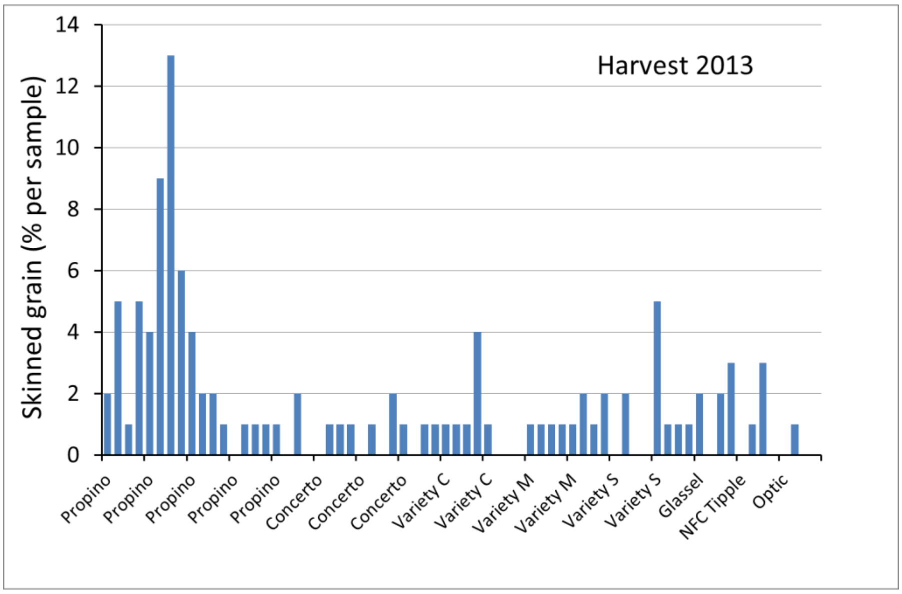


Fig. 2. Variation in percent of skinned grain in sub-samples from a commercial malting intake from central-east Scotland in 2013. Legend as in Fig.1.

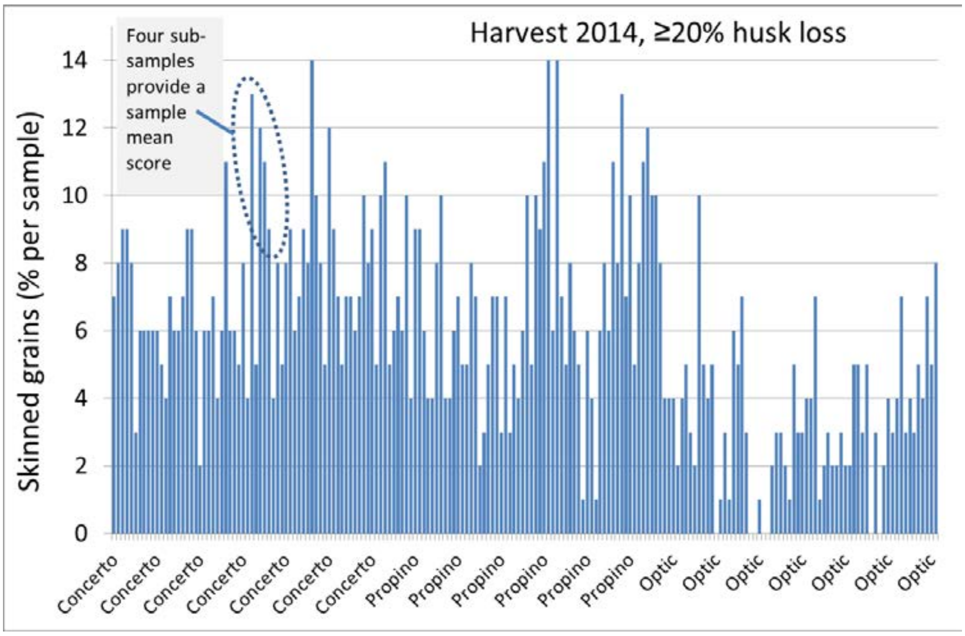


Fig. 3. Variation in percent of skinned grain in sub-samples from SRUC large plots at Bush Estate in 2013. Legend as in Fig. 1.

4.2. Variety trials

4.2.1. Recommended List and National List trials, harvest 2015

There was significant variation in skinning among varieties in NL (Table 3) and RL (Table 4) trials, with % skinning scores ranging from less than 10% to above 25%. In both trials, there was a small % difference in skinning between the two sites at Aberdeen and Perth. Site by variety interaction was also significant in the RL and NL trials. Although differential variety performance between the two sites makes interpretation of variety skinning scores (as a main effect) incomplete, varieties at the extremes of the skinning range were consistent in their resistance or susceptibility.

Table 3. Analysis of variance on grain skinning among varieties at two BSPB NL sites in Aberdeen and Perth, harvest 2015. (a) ANOVA table using arcsine transformed skinning data, (b) grand mean and site means for % skinning and (c) Rank order in % skinning among varieties; letters denote significant variety differences using Duncan's multiple comparison of transformed data.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Site	1	80.014	1.799	12.3	<.001
Variety	23	3215.854	72.287	21.5	<.001
Site*Variety	22	607.532		4.25	<.001
Residual	92	598.421			
Total	140	4448.731			

(b) Grand mean and site means for % skinning.

Grand mean 22.52

	Aberdeen	Perth
Site means	21.77	23.27

(c) Variety rank order in % skinning. Apart from several controls, NL candidates are coded from NL-A to NL-T.

Variety	Skinning %	Significance (based on arcsine transformed data)
NL-A	7.5	a
NFC Tipple	7.67	a
NL-B	8.5	ab
NL-C	9.67	abc
NL-D	10.17	abcd
NL-E	10.83	abcde
NL-F	11.17	bcdef
NL-G	12.0	bcdef
NL-H	12.0	bcdef
NL-I	12.67	cdef
NL-J	12.67	cdef
NL-K	12.83	cdef
Concerto	14.0	Defg
Odyssey	14.67	Efgh
NL-L	15.0	Fgh
NL-M	17.5	Ghi
Propino	18.0	Ghi
NL-N	18.33	Hi
NL-O	19.33	I
NL-P	19.83	I
NL-Q	20.12	I
NL-R	22.17	Ij
NL-S	25.17	j
NL-T	35.5	k

Table 4. Analysis of variance on grain skinning among varieties at two BSPB RL sites in Aberdeen and Perth, harvest 2015. (a) ANOVA table using arcsine transformed skinning data, (b) grand mean and site means for % skinning and (c) Rank order in % skinning among varieties; letters denote significant variety differences using Duncan's multiple comparison of transformed data.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Site	1	257.131	9.151	34.14	<.001
Variety	17	1960.19	69.765	15.31	<.001
Site*Variety	15	418.836		3.71	<.001
Residual	66	497.038			
Total	101	2809.724			

(b) Grand mean and site means for % skinning.

Grand mean	23.08	
	Aberdeen	Perth
Site means	21.53	24.62

(c) Variety rank order in % skinning. Apart from several controls, RL varieties are coded from RL-A to RL-N.

Variety	Skinning %	Significance (based on transformed data)
NFC Tipple	6.0	a
RL-A	9.5	ab
RL-B	10.0	ab
RL-C	10.17	b
RL-D	12.0	bc
RL-E	12.33	bc
RL-F	13.67	bcd
RL-G	14.33	cde
RL-H	15.67	cde
Odyssey	16.17	cde
RL-I	17.5	def
RL-J	18.0	def
Concerto	18.5	efg
RL-K	18.5	efg
RL-L	22.0	fgh
RL-M	22.83	gh
RL-N	24.0	h
Propino	26.17	h

4.2.2. Variety and sowing (harvest) date (Loirston Charitable Trust), harvests 2012 and 2013

Harvest 2012

In 2012, there were significant effects of variety and sowing (harvest) date on grain yield, with late sowing having a yield penalty of 2 t/ha (Table 5). In 2012, all TGWs and specific weights were relatively low at less than 45 g and 60 kg/hl, respectively (Tables 6 and 7). Late sowing significantly decreased both TGW (Table 6) and specific weight (Table 7) compared to early sowing. TGW among varieties ranged from 39.3 g to 44.3 g, with specific weight ranging from 54.0 kg/hl to 59.2 kg/hl. Screenings varied significantly among varieties and was higher significantly in later sown crops (Table 8).

In 2012, grain skinning was relatively high and the overall trial mean was above 30%. Skinning varied significantly among varieties (Table 9). There was, however, a significant variety by sowing date interaction. Overall, the varieties, Optic, Moonshine, NFC Tipple and Westminster had least skinning, whilst Overture, Odyssey and Propino had most.

Table 5. Analysis of variance for effects of sowing date and variety choice on grain yield. (a) ANOVA table and (b) mean yield for different treatments, with l.s.d. Data are from an SRUC trial site in Aberdeenshire in 2012.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	60.65884	91.956	1391.55	<.001
Variety	14	2.34091	3.549	3.84	0.001
Sowing*Variety	14	1.61636		2.65	0.013
Residual	29	1.26413			
Total	59	65.96473			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 5.50

Sowing date	Early	Late			l.s.d.
	6.51	4.5			0.11
Belgravia	Chronicle	Concerto	Garner	Moonshine	l.s.d
5.33	5.71	5.79	5.68	5.52	0.302
NFC Tipple	Odyssey	Optic	Overture	Propino	
5.3	5.68	5.29	5.4	5.61	
Quench	Shuffle	Summit	Waggon	Westminster	
5.3	5.47	5.64	5.69	5.1	

Table 6. Analysis of variance for effects of sowing date and variety choice on thousand grain weight. (a) ANOVA table and (b) mean TGW for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2012.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	280.161	45.210	98.87	<.001
Variety	14	205.392	33.144	5.18	<.001
Sowing*Variety	14	48.676		1.23	0.309
Residual	29	82.179			
Total	59	619.69			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 40.7

Sowing date	Early	Late			l.s.d.
	42.9	38.6			0.89
Belgravia	Chronicle	Concerto	Garner	Moonshine	l.s.d
39.8	39.3	40.3	42.3	41.7	2.43
NFC Tipple	Odyssey	Optic	Overture	Propino	
40.6	40.4	40.5	38.6	42.5	
Quench	Shuffle	Summit	Waggon	Westminster	
37.5	44.3	38.5	43.7	41	

Table 7. Analysis of variance for effects of sowing date and variety choice on grain specific weight. (a) ANOVA table and (b) mean specific weight for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2012.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	853.528	81.456	420.37	<.001
Variety	14	101.387	9.676	3.57	0.002
Sowing*Variety	14	33.897		1.19	0.332
Residual	29	58.882			
Total	59	1047.835			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 55.92

Sowing date	Early	Late			l.s.d.
	59.69	52.15			0.752

Belgravia	Chronicle	Concerto	Garner	Moonshine	l.s.d.
56.85	54.82	56.5	54.49	55.75	2.061
NFC Tipple	Odyssey	Optic	Overture	Propino	
55.22	54	59.2	55.47	56.8	
Quench	Shuffle	Summit	Waggon	Westminster	
54.65	54.89	56.41	56.47	57.24	

Table 8. Analysis of variance for effects of sowing date and variety choice on screenings. (a) ANOVA table and (b) mean screenings for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2012.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	211.313	37.336	100.86	<.001
Variety	14	201.112	35.534	6.86	<.001
Sowing*Variety	14	92.112		3.14	0.004
Residual	29	60.757			
Total	59	565.977			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 9.87

Sowing date	Early	Late			l.s.d.
	8.00	11.75			0.764

Belgravia	Chronicle	Concerto	Garner	Moonshine	l.s.d.
10.03	9.43	8	10.48	8.63	2.093
NFC Tipple	Odyssey	Optic	Overture	Propino	
12	9.9	11.8	9.33	6.6	
Quench	Shuffle	Summit	Waggon	Westminster	
12.63	7	12.95	9.7	9.65	

Table 9. Analysis of variance for effects of sowing date and variety choice on grain skinning. (a) ANOVA table and (b) mean grain skinning for different treatments using an arcsine transformation of skinning data. (c) Rank order in skinning % among varieties; letters denote varieties that are significantly different using Duncan's multiple comparison of the arcsine transformed data. Data are from an SRUC trial site in Aberdeenshire in 2012.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sown	1	727.678	24.735	602.02	<.001
Variety	14	853.781	29.022	50.45	<.001
Sowing*Variety	14	1262.354		74.6	<.001
Residual	29	35.053			
Total	59	2941.881			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 31.93					
Sowing Date	Early 28.45	Late 35.42			l.s.d. 0.581
Belgravia	Chronicle	Concerto	Garner	Moonshine	l.s.d
31.34	31.31	31.54	32.96	28.08	1.59
NFC Tipple	Odyssey	Optic	Overture	Propino	
28.69	39.16	24.49	35.08	39.21	
Quench	Shuffle	Summit	Waggon	Westminster	
30.14	34.45	31.82	31.18	29.58	

(c) Variety rank order.

Variety	Skinning %	Significance (from Arcsine transformation)
Optic	17.75	a
Moonshine	22.88	b
NFC Tipple	23.12	bc
Westminster	24.88	bcd
Quench	26.38	cde
Waggon	26.88	def
Belgravia	27.12	ef
Chronicle	27.62	ef
Concerto	27.75	ef
Summit	28.25	ef
Garner	29.62	fg
Shuffle	32.75	gh
Overture	34.25	h
Odyssey	40	i
Propino	40	i

Harvest 2013

In 2013, grain yield, TGW and specific weight were substantially higher than in 2012 (Table 10). Yield varied significantly among varieties, but not by sowing date, though later sown crops had a 0.2 t/ha yield advantage on average. TGW varied significantly among varieties from 40.6 g to 50.5 g and was significantly higher in the early sown crops (Table 11). Specific weight was significantly different among varieties, and ranged from 57.3 kg/hl to 64.79 kg/hl (Table 12). Early sowing significantly increased specific weight compared to late sowing. Screenings were lower in 2013 compared to 2012, but variation among varieties and sowing date were still significant.

Skinning was lower in 2013 than in 2012, but variation among varieties was significant and later sown crops had higher levels of skinning. There was a significant variety by sowing interaction, though varieties with least skinning were Westminster, Belgravia, Waggon, NFC Tipple, Rynchostar and Optic, whilst those with most skinning were Propino, Glassel, Tesla, Shuffle and Overture.

Table 10. Analysis of variance for effects of sowing date and variety choice on grain yield. (a) ANOVA table and (b) mean yield for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2013.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	0.83	2.346	2.31	0.136
Variety	19	14.1475	39.988	2.07	0.027
Sowing*Variety	19	6.0793		0.89	0.595
Total	79	35.3792			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 6.95

Sowing date	Early	Late			l.s.d.
	6.84	7.05			0.271
Belgravia	Chronicle	Concerto	Crooner	Garner	l.s.d.
6.83	6.75	7.24	6.65	7.24	0.857
Glassel	Montoya	Moonshine	NFC Tipple	Odyssey	
6.89	6.57	6.57	6.51	7.37	
Optic	Overture	Propino	Quench	Rynchostar	
6.85	7.24	7.43	7.5	6.21	
Sannette	Shuffle	Tesla	Waggon	Westminster	
6.25	7.64	6.61	7.1	7.48	

Table 11. Analysis of variance for effects of sowing date and variety choice on thousand grain weight. (a) ANOVA table and (b) mean TGW for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2013.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	106.491	13.996	29.66	<.001
Variety	19	389.751	51.224	5.71	<.001
Sowing*Variety	19	49.896		0.73	0.765
Residual	39	140.044			
Total	79	760.874			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 45.5

Sowing date	Early	Late			l.s.d.
	46.6	44.3			0.86
Belgravia	Chronicle	Concerto	Crooner	Garner	l.s.d
42.7	43.2	44.4	43.7	47.1	2.71
Glassel	Montoya	Moonshine	NFC Tipple	Odyssey	
40.6	45.6	45.6	46.4	45.5	
Optic	Overture	Propino	Quench	Rynchostar	
46.5	44.6	47.5	43.8	42.7	
Sannette	Shuffle	Tesla	Waggon	Westminster	
47	50.4	46.5	47.5	47.8	

Table 12. Analysis of variance for effects of sowing date and variety choice on grain specific weight. (a) ANOVA table and (b) mean specific weight for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2013.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	1.266	149.6045	160	<.001
Variety	19	24.051	12.8468	13.74	<.001
Sowing*Variety	19		1.3113	1.4	0.182
Residual	39		0.935		
Total	79	487.5849			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 61.16

Sowing date	Early	Late			l.s.d.
	62.53	59.79			0.437

Belgravia	Chronicle	Concerto	Crooner	Garner	l.s.d
60.54	61.53	61.53	62.08	59.86	1.383
Glassel	Montoya	Moonshine	NFC Tipple	Odyssey	
58.16	60.98	62.46	62.85	59.9	
Optic	Overture	Propino	Quench	Rynchostar	
64.79	61.03	61.35	61.1	60.49	
Sannette	Shuffle	Tesla	Waggon	Westminster	
59.81	61.24	57.3	61.61	64.64	

Table 13. Analysis of variance for effects of sowing date and variety choice on screenings. (a) ANOVA table and (b) mean screenings for different treatments. Data are from an SRUC trial site in Aberdeenshire in 2013.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	33.6701	51.492	156.16	<.001
Variety	19	17.4714	26.719	4.26	<.001
Sowing*Variety	19	4.6624		1.14	0.355
Residual	39	8.4089			
Total	79	65.3889			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 2.084

Sowing date	Early	Late			l.s.d.
	1.435	2.732			0.21
Belgravia	Chronicle	Concerto	Crooner	Garner	l.s.d
2.175	2.475	1.925	2.7	2.925	0.6641
Glassel	Montoya	Moonshine	NFC Tipple	Odyssey	
2.45	1.55	1.65	1.75	2.1	
Optic	Overture	Propino	Quench	Rynchostar	
1.525	2.1	1.375	2.3	2.8	
Sannette	Shuffle	Tesla	Waggon	Westminster	
2.375	1.225	2.225	2.3	1.75	

Table 14. Analysis of variance for effects of sowing date and variety choice on grain skinning. (a) ANOVA table and (b) mean grain skinning for different treatments using an arcsine transformation of skinning data. (c) Rank order in skinning % among varieties; the letters denote varieties that are significantly different using Duncan's multiple comparison of the arcsine transformed data. Data are from an SRUC trial site in Aberdeenshire in 2013.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Sowing date	1	327.397	23.174	190.15	<.001
Variety	19	834.389	59.061	25.51	<.001
Sowing*Variety	19	183.817		5.62	<.001
Residual	39	67.15			
Total	79	1412.766			

(b) Treatment means for sowing date and variety, with l.s.d.

Grand mean 15.73

Sowing Date	Early	Late			l.s.d.
	13.71	17.75			0.593
Belgravia	Chronicle	Concerto	Crooner	Garner	l.s.d.
11.49	15.3	16.81	14.9	14.79	1.877
Glassel	Montoya	Moonshine	NFC Tipple	Odyssey	
19.31	15.72	14.84	13.03	15.55	
Optic	Overture	Propino	Quench	Rynchostar	
13.53	22.69	17.91	17.04	13.63	
Sannette	Shuffle	Tesla	Waggon	Westminster	
15.12	20.83	20.63	11.67	9.76	

(c) Variety rank order.

Variety	Skinning %	Significance (from arcsine transformation)
Westminster	2.875	a
Belgravia	4.00	ab
Waggon	4.375	abc
NFC Tipple	5.125	bcd
Rynchostar*	5.625	cdef
Optic*	5.75	cde
Garner	6.75	defg
Moonshine	6.75	defg
Crooner	6.875	defgh
Sannette	6.875	defgh
Odyssey	7.375	efgh
Chronicle	7.50	efgh
Montoya	7.75	fgh
Concerto	8.50	ghi
Quench	8.625	hi
Propino	9.625	ij
Glassel	11.00	jk
Tesla	12.625	k
Shuffle	12.875	kl
Overture	15.125	l

*note that Rhynchostar and Optic were reversed in rank order using the arcsine transformation.

4.2.3. Skinning assessment of BBSRC CIRC trial 2013

The rank order in skinning in 100 varieties is presented in Fig. 4. The left-hand side figure ranks varieties that range from zero to 8% skinning, whilst in the right-hand figure the range is from 8% to > 30% skinned. Aramir and Chad had zero skinning, whilst Concerto, Braemar, Cristalia, Scarlett and Cropton had skinned more than 30%. Full analysis of these data will be presented in a publication of multi-site trials from the BBSRC CIRC project.

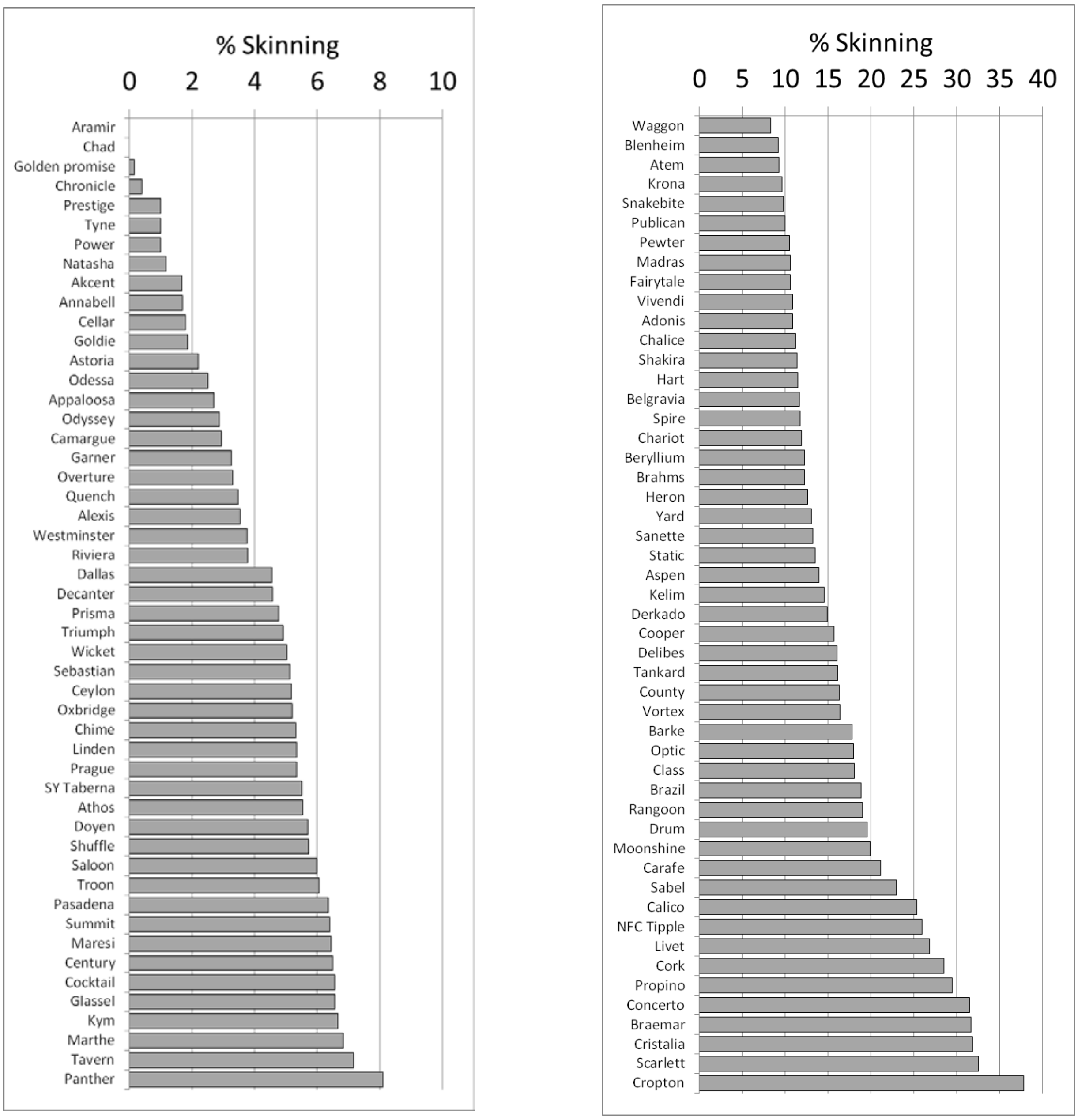


Fig. 4. Variation in skinning among 100 varieties from a BBSRC CIRC funded field trial in Midlothian, near Edinburgh, 2013. Each bar is the mean percentage of 4 sub-samples of 100 grains.

4.3. Agronomy trials for screening of grain skinning

4.3.1. Nitrogen, fungicide, PGR and variety effects on yield and skinning; at Scottish Agronomy trials centres in Glenrothes and Ellon 2014 and 2015

Nitrogen fertiliser and variety choice had significant effects on grain yield, whilst fungicide programme and PGR had none (Table 15). There were small, but significant, differences in grain % moisture content between nitrogen treatments and variety; the higher rate of nitrogen at 170 kg N/ha and the variety Optic had relatively high % moisture (Table 16). There were no significant effects of fungicide programme or PGR on grain % moisture.

There was a small, but significant, decrease in skinning when nitrogen fertiliser was increased from 130 to 170 N kg/ha (Table 17). There were no significant effects of fungicide programme or PGR on skinning. There was a highly significant effect of variety on skinning with Optic at 13.1%, Concerto 20.9%, Propino 25.8%. The rank order in % skinning among all treatment combinations (nitrogen x fungicide x PGR x variety) was clustered by variety, with all Optic treatment combinations being < 7% skinned and all Propino treatment combinations > 16% skinned (Table 17c).

Table 15. (a) Analysis of variance for the effects of agronomic treatments on grain yield and (b) mean yield (t/ha) for different nitrogen, fungicide, PGR and variety treatments. Data are from two Scottish Agronomy trial sites (Glenrothes, Fife and Ellon, Aberdeenshire) in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Nitrogen	1	1.432	1.394	6.280	0.013
Fungicide	1	0.005	0.005	0.020	0.885
PGR	1	0.778	0.757	3.410	0.067
Variety	2	9.611	9.360	21.070	<.001
Two-way interaction					
Nitrogen*Fungicide	1	0.366		1.600	0.207
Nitrogen*PGR	1	0.097		0.430	0.515
Fungicide*PGR	1	0.093		0.410	0.525
Nitrogen*Variety	2	0.033		0.070	0.930
Fungicide*Variety	2	0.304		0.670	0.515
PGR*Variety	2	1.335		2.930	0.056
Residual	170	38.771			
Total	191	102.688			

(b) Treatment means and l.s.d.

Grand mean 7.416				l.s.d.
Nitrogen	130	170		
	7.33	7.50		0.14
Fungicide	Proline	Siltra		
	7.42	7.41		0.14
PGR	Moddus	No PGR		
	7.48	7.35		0.14
Variety	Concerto	Optic	Propino	
	7.16	7.38	7.71	0.17

Table 16. (a) Analysis of variance for agronomic treatments on grain moisture % at harvest and (b) mean grain moisture (%) for different nitrogen, fungicide, PGR and variety treatments. Data are from two Scottish Agronomy trial sites (Glenrothes, Fife and Ellon, Aberdeenshire) in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Nitrogen	1	3.882	0.601	5.470	0.020
Fungicide	1	0.001	0.000	0.000	0.966
PGR	1	0.359	0.056	0.510	0.478
Variety	2	17.886	2.768	12.610	<.001
Two-way interaction					
Nitrogen*Fungicide	1	0.921		1.300	0.256
Nitrogen*PGR	1	0.531		0.750	0.388
Fungicide*PGR	1	0.000		0.000	0.993
Nitrogen*Variety	2	1.581		1.110	0.330
Fungicide*Variety	2	0.010		0.010	0.993
PGR*Variety	2	0.235		0.170	0.847
Residual	170	120.549			
Total	191	646.079			

(b) Treatment means and l.s.d.

Grand mean 18.753

				l.s.d.
Nitrogen	130	170		
	18.61	18.895		0.2399
Fungicide	Proline	Siltra		
	18.755	18.75		0.2399
PGR	Moddus	No PGR		
	18.796	18.709		0.2399
Variety	Concerto	Optic	Propino	
	18.655	19.166	18.437	0.2939

Table 17. (a) Analysis of variance for agronomic treatments on grain skinning (arcsine transformed from the original % data) at harvest and (b) mean grain skinning levels for different nitrogen, fungicide, PGR and variety treatments. (c) Rank order in skinning % among treatments; the letters denote treatments that are significantly different using Duncan's multiple comparison of the arcsine transformed data. Data are from two Scottish Agronomy trial sites (Glenrothes, Fife and Ellon, Aberdeenshire) in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Nitrogen	1	42.347	0.388	6.110	0.014
Fungicide	1	0.615	0.006	0.090	0.766
PGR	1	0.345	0.003	0.050	0.824
Variety	2	5313.997	48.709	383.250	<.001
Two-way interaction					
Nitrogen*Fungicide	1	9.885		1.430	0.234
Nitrogen*PGR	1	0.108		0.020	0.901
Fungicide*PGR	1	2.756		0.400	0.529
Nitrogen*Variety	2	6.733		0.490	0.616
Fungicide*Variety	2	9.362		0.680	0.510
PGR*Variety	2	30.049		2.170	0.118
Residual	170	1178.56			
Total	191	10909.778			

(b) Treatment means and l.s.d.

Grand mean 19.94

				l.s.d.
Nitrogen	130	170		
	20.41	19.47		0.75
Fungicide	Proline	Siltra		
	19.88	19.99		0.75
PGR	Moddus	No PGR		
	19.9	19.98		0.75
Variety	Concerto	Optic	Propino	
	20.92	13.06	25.83	0.919

(c) Treatment (agronomy and variety) rank order.

Variety	Nitrogen rate	Fungicide	PGR	Skinning (%)	Significance (from arcsine transformation)
Optic	170 Kg/N	Siltra	Moddus	4.44	a
Optic	170 Kg/N	Proline	Moddus	5.22	a
Optic	130 Kg/N	Proline	Moddus	5.46	a
Optic	130 Kg/N	Siltra	Moddus	5.73	a
Optic	170 Kg/N	Siltra	No PGR	5.8	a
Optic	170 Kg/N	Proline	No PGR	5.82	a
Optic	130 Kg/N	Proline	No PGR	6.19	a
Optic	130 Kg/N	Siltra	No PGR	6.69	a
Concerto	170 Kg/N	Siltra	No PGR	12.76	b
Concerto	170 Kg/N	Proline	Moddus	12.89	b
Concerto	130 Kg/N	Siltra	Moddus	13.11	b
Concerto	170 Kg/N	Siltra	Moddus	13.23	b
Concerto	130 Kg/N	Siltra	No PGR	13.54	b
Concerto	130 Kg/N	Proline	No PGR	13.67	b
Concerto	170 Kg/N	Proline	No PGR	14.44	b
Concerto	130 Kg/N	Proline	Moddus	14.61	bc
Propino	170 Kg/N	Proline	No PGR	17.07	cd
Propino	170 Kg/N	Siltra	No PGR	17.52	cde
Propino	130 Kg/N	Proline	No PGR	18.76	de
Propino	170 Kg/N	Siltra	Moddus	18.85	de
Propino	130 Kg/N	Proline	Moddus	19.64	de
Propino	170 Kg/N	Proline	Moddus	19.94	de
Propino	130 Kg/N	Siltra	Moddus	21.51	e
Propino	130 Kg/N	Siltra	No PGR	22.42	e

4.3.2. Nitrogen, fungicide, PGR and variety effects on yield and skinning; at SRUC trials centre, Midlothian, 2014 and 2015

Varieties and fungicide treatment had significant effects on grain yield, whilst nitrogen fertiliser and PGR did not (Table 18). Crops grown without fungicide had significantly lower grain % moisture than those with fungicide at harvest (Table 19). There were highly significant effects of variety and fungicide on TGW (Table 20) and screenings (Table 22), and a highly significant effect of variety on specific weight (Table 21). Otherwise, there were no significant effects of agronomic treatments on TGW, specific weight or screenings.

The effect of variety on skinning was highly significant, whilst nitrogen fertiliser, fungicide and PGR had no significant effects on skinning (Table 23). The treatment combinations of fungicide x PGR x variety were clustered by variety with all Optic treatments being < 7.5% skinned and all Propino treatments > 20% skinned (Table 23c). Note that the nitrogen fertiliser treatment was not included in the rank order of treatment combinations as this factor was analysed at a different statistical level in the split-plot ANOVA.

There was no evidence for any significant relationships between grain size (TGW), specific weight or screenings and grain skinning, as influenced by agronomic treatments (Fig. 5). Within varieties, there was no evidence for relationships between TGW, specific weight or screenings and skinning, as influenced by agronomic treatments (data not shown). There was a large seasonal effect on skinning, with 2014 being a low skinning year and 2015 relatively high (see Fig. 5).

Table 18. (a) Analysis of variance for agronomic treatments on grain yield (t/ha) at harvest and (b) mean yield for different nitrogen, fungicide, PGR and variety treatments. Data are from the SRUC Midlothian trial site in 2014 and 2015.

(a) ANOVA Table

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	0.0464	0.051	0.18	0.698
Residual	3	0.7625		2.28	
Split-plot					
Fungicide	1	63.0761	69.463	564.79	<.001
PGR	1	0.0295	0.032	0.26	0.609
Variety	2	4.5968	5.062	20.58	<.001
Two-way interaction					
Nitrogen*Fungicide	1	1.7192		15.39	<.001
Nitrogen*PGR	1	0.0277		0.25	0.620
Fungicide*PGR	1	0.1108		0.99	0.322
Nitrogen*Variety	2	0.0163		0.07	0.930
Fungicide*Variety	2	1.4338		6.42	0.003
PGR*Variety	2	0.332		1.49	0.233
Residual	75	8.376			
Total	95	90.805			

(b) Treatment means and l.s.d.

Grand mean 7.44

				l.s.d.
Nitrogen (kg/ha)	120	170		
	7.46	7.41		0.327
Fungicide	None	Full		
	6.62	8.25		0.136
PGR	None	Full		
	7.42	7.45		0.136
Variety	Concerto	Optic	Propino	
	7.66	7.14	7.51	0.166

Table 19. (a) Analysis of variance for agronomic treatments on grain moisture (%) at harvest and (b) mean grain moisture for different nitrogen, fungicide, PGR and variety treatments. Data are from the SRUC Midlothian trial site in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	2.7338	4.456	0.55	0.511
Residual	3	14.8421		23.47	
Split-plot					
Fungicide	1	9.1267	14.876	43.30	<.001
PGR	1	0.0817	0.133	0.39	0.536
Variety	2	0.1433	0.234	0.34	0.713
Two-way interaction					
Nitrogen*Fungicide	1	2.3438		11.12	0.001
Nitrogen*PGR	1	0.0004		0.00	0.965
Fungicide*PGR	1	0.4267		2.02	0.159
Nitrogen*Variety	2	0.3675		0.87	0.422
Fungicide*Variety	2	2.9658		7.04	0.002
PGR*Variety	2	0.3233		0.77	0.468
Residual	75	15.8075			
Total	95	61.3533			

(b) Treatment means and l.s.d.

Grand mean 15.792

				l.s.d.
Nitrogen (kg/ha)	120	170		
	15.623	15.96		1.4449
Fungicide	None	Full		
	15.483	16.1		0.1867
PGR	None	Full		
	15.821	15.763		0.1867
Variety	Concerto	Optic	Propino	
	15.738	15.813	15.825	0.2286

Table 20. (a) Analysis of variance for agronomic treatments on grain thousand grain weight (g) at harvest and (b) mean TGW for different nitrogen, fungicide, PGR and variety treatments. Data are from the SRUC Midlothian trial site in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	13.353	1.141	0.48	0.538
Residual	3	83.31		5.7	
Split-plot					
Fungicide	1	333.975	28.534	68.5	<.001
PGR	1	1.276	0.109	0.26	0.61
Variety	2	139.57	11.925	14.31	<.001
Two-way interaction					
Nitrogen*Fungicide	1	0.317		0.07	0.799
Nitrogen*PGR	1	37.269		7.64	0.007
Fungicide*PGR	1	0.848		0.17	0.678
Nitrogen*Variety	2	5.285		0.54	0.584
Fungicide*Variety	2	5.934		0.61	0.547
PGR*Variety	2	11.681		1.2	0.308
Residual	75	365.659			
Total	95	1170.431			

(b) Treatment means and l.s.d.

Grand mean 53.2				l.s.d.
Nitrogen (kg/ha)	120	170		
	53.6	52.8		3.42
Fungicide	None	Full		0.9
	51.3	55.1		
PGR	None	Full		
	53.1	53.3		0.9
Variety	Concerto	Optic	Propino	
	51.8	53.1	54.7	1.1

Table 21. (a) Analysis of variance for agronomic treatments on grain specific weight (kg/hl) at harvest and (b) mean specific weight for different nitrogen, fungicide, PGR and variety treatments. Data are from the SRUC Midlothian trial site in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	7.3704	3.024	0.41	0.569
Residual	3	54.3012		18.46	
Split-plot					
Fungicide	1	3.0104	1.235	3.07	0.084
PGR	1	0.0017	0.001	0	0.967
Variety	2	93.1994	38.244	47.53	<.001
Two-way interaction					
Nitrogen*Fungicide	1	0.8438		0.86	0.357
Nitrogen*PGR	1	0.2017		0.21	0.651
Fungicide*PGR	1	0.0417		0.04	0.837
Nitrogen*Variety	2	0.6665		0.34	0.713
Fungicide*Variety	2	2.584		1.32	0.274
PGR*Variety	2	0.2815		0.14	0.867
Residual	75	73.5396			
Total	95	243.6963			

(b) Treatment means and l.s.d.

Grand mean 68.31

				l.s.d.
Nitrogen (kg/ha)	120	170		
	68.58	68.03		2.764
Fungicide	None	Full		
	68.13	68.48		0.403
PGR	None	Full		
	68.3	68.31		0.403
Variety	Concerto	Optic	Propino	
	67.69	69.7	67.53	0.493

Table 22. (a) Analysis of variance for agronomic treatments on grain screenings (% through a 2.5 mm sieve) at harvest and (b) mean grain screenings for different nitrogen, fungicide, PGR and variety treatments. Data are from the SRUC Midlothian trial site in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	0.5251	0.330	0.97	0.397
Residual	3	1.6186		0.71	
Split-plot					
Fungicide	1	56.8876	35.792	74.88	<.001
PGR	1	1.4259	0.897	1.88	0.175
Variety	2	21.1652	13.316	13.93	<.001
Two-way interaction					
Nitrogen*Fungicide	1	0.4676		0.62	0.435
Nitrogen*PGR	1	0.0009		0	0.972
Fungicide*PGR	1	0.0876		0.12	0.735
Nitrogen*Variety	2	6.014		3.96	0.023
Fungicide*Variety	2	8.0402		5.29	0.007
PGR*Variety	2	1.2206		0.8	0.452
Residual	75	56.9811			
Total	95	158.9399			

(b) Treatment means and l.s.d.

Grand mean 3.149

				l.s.d.
Nitrogen (kg/ha)	120	170		
	3.075	3.223		0.4772
Fungicide	None	Full		
	3.919	2.379		0.3544
PGR	None	Full		
	3.271	3.027		0.3544
Variety	Concerto	Optic	Propino	
	3.719	3.159	2.569	0.4341

Table 23. (a) Analysis of variance for agronomic treatments on grain skinning (arcsine transformed from the original % data) at harvest and (b) mean grain skinning % (arcsine transformed) for different nitrogen, fungicide, PGR and variety treatments. (c) Rank order in skinning % among fungicide, PGR and variety treatments (split-plot level); the letters denote treatments that are significantly different using Duncan's multiple comparison of the arcsine transformed data. Data are from an SRUC trial site in Midlothian in 2014 and 2015.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Nitrogen	1	17.8	0.185	0.63	0.484
Residual	3	84.39		1.17	
Split-plot					
Fungicide	1	30.56	0.318	1.28	0.262
PGR	1	1.66	0.017	0.07	0.793
Variety	2	2596.11	26.975	54.18	<.001
Two-way interaction					
Nitrogen*Fungicide	1	2.82		0.12	0.732
Nitrogen*PGR	1	2.36		0.1	0.754
Fungicide*PGR	1	22.99		0.96	0.33
Nitrogen*Variety	2	37.51		0.78	0.461
Fungicide*Variety	2	16.05		0.33	0.716
PGR*Variety	2	2.39		0.05	0.951
Residual	75	1796.88			
Total	95	9624.21			

(b) Treatment means and l.s.d.

Grand mean 20.77				
Nitrogen (kg/ha)	120	170		l.s.d.
	20.34	21.2		3.445
Fungicide	None	Full		
	21.33	20.2		1.99
PGR	None	Full		
	20.64	20.9		1.99
Variety	Concerto	Optic	Propino	
	21.93	13.9	26.47	2.438

(c) Treatment (agronomy and variety) rank order.

Variety	Fungicide	PGR	Skinning (%)	Significance (from arcsine transformation)
Optic	Full	None	5.56	a
Optic	None	None	6.22	a
Optic	Full	Full	6.62	a
Optic	None	Full	7.25	a
Concerto	Full	None	12.94	b
Concerto	Full	Full	13.66	b
Concerto	None	Full	16.44	bc
Concerto	None	None	16.84	bc
Propino	Full	None	20.69	bc
Propino	None	Full	21.64	bc
Propino	Full	Full	22.59	c
Propino	None	None	24.69	c

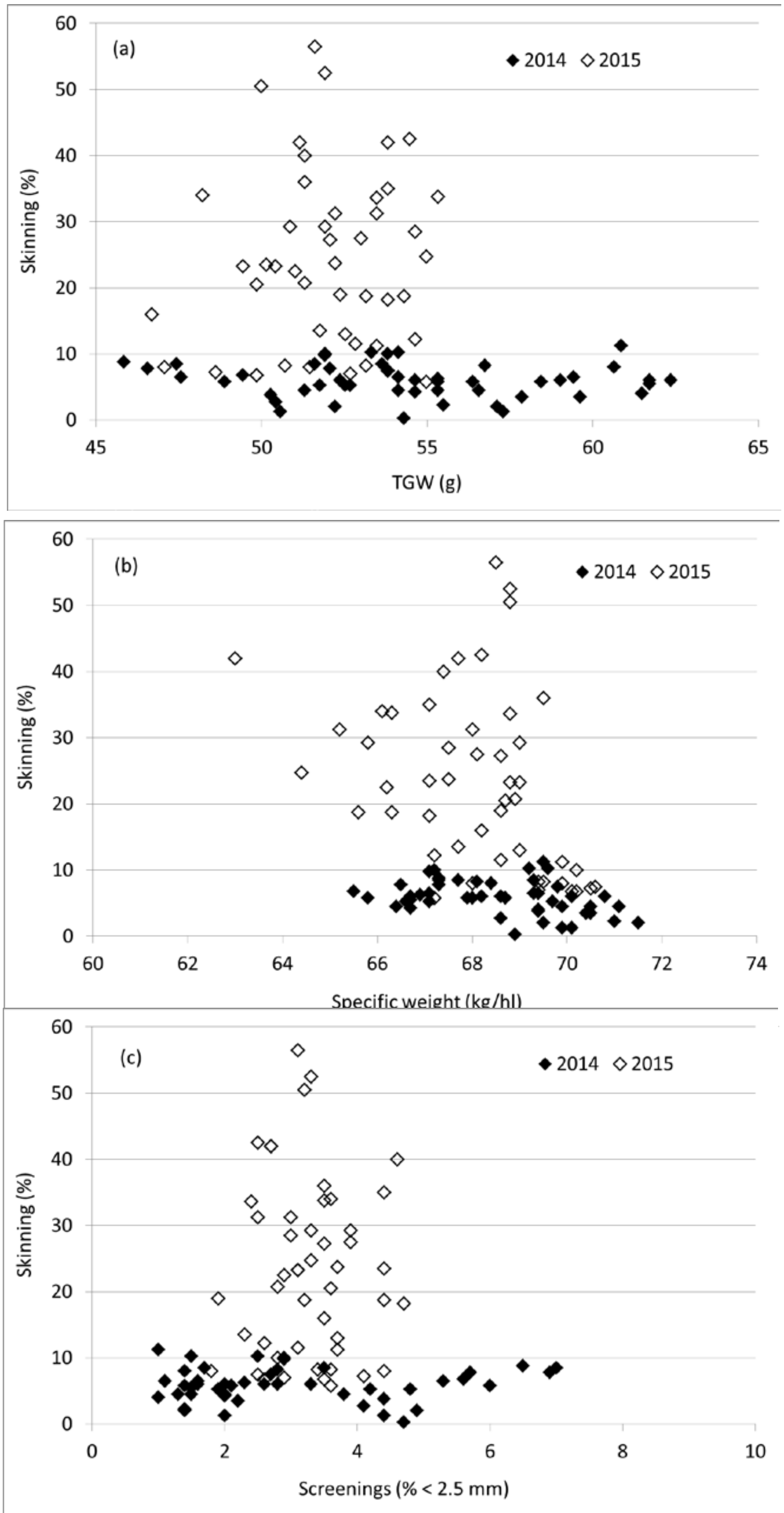


Fig. 5. Grain skinning % plotted against (a) thousand grain weight, (b) specific weight and (c) screenings in seasons 2014 (dark symbol) and 2015 (open symbol). Data points are replicates of harvested from each agronomic treatment combination i.e. variety, nitrogen fertiliser, fungicide and PGR.

4.3.3. The effects of combine harvester settings on grain skinning from trials in Midlothian 2014, 2015 and 2016

Quench and Sanette, harvest 2014

There were no significant effects of combine drum speed or concave setting on TGW (Table 24) or specific weight (Table 25) in either variety, Quench or Sanette. Quench had higher levels of skinning than Sanette, but not significantly so (Table 26). Skinning increased significantly with an increase in drum speed from 800 to 1600 rpm. Skinning increased with an increase in concave tightness, but not significantly so (Table 26).

Table 24. (a) Analysis of variance for different combine harvester treatments on thousand grain weight (g) in varieties Quench and Sanette and (b) mean TGW different combine settings. Data are from an SRUC trial site in Midlothian trial site in 2014.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Variety	1	3.844	10.541	1.1	0.484
Residual	1	3.481		5.3	
Sub-plot					
Treatment	9	10.2413	28.085	1.73	0.154
Variety*Treatment	9	7.0576		1.19	0.357
Residual	18	11.8299			
Total	39	36.466			

(b) Treatment means for variety and combine settings.

Grand mean 55.1

Variety	Quench	Sanette	l.s.d.
	54.8	55.4	7.5

Combine setting treatments		
Drum speed (rpm)		
800	55.4	1.2
1000	54.7	
1200	55.8	
1400	54.3	
1600	55.1	
Concave setting (5 = tightest)		
1	55	
2	55.7	
3	55.1	
4	55.6	
5	54.4	

Table 25. (a) Analysis of variance for different combine harvester treatments on grain specific weight (kg/hl) in varieties Quench and Sanette and (b) mean specific weight at different combine settings. Data are from an SRUC trial site in Midlothian trial site in 2014.

(a) ANOVA table.

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Variety	1	1.849	7.161	2.05	0.388
Residual	1	0.9		1.5	
Split-plot					
Treatment	9	6.174	23.913	1.14	0.385
Variety*Treatment	9	6.016		1.11	0.403
Residual	18	10.816			
Total	39	25.819			

Grand mean 67.14

Variety	Quench	Sanette	l.s.d.
	67.36	66.93	3.812
Combine setting treatments			
Drum speed (rpm)			
800	67.12		1.152
1000	67.38		
1200	66.35		
1400	67.65		
1600	66.90		
Concave setting (5 = tightest)			
1	67.42		
2	67.22		
3	66.62		
4	67.20		
5	67.57		

Table 26. (a) Analysis of variance for different combine harvester treatments on grain skinning (arcsine transformed from the original % data) in varieties Quench and Sanette and (b) mean grain skinning scores (arcsine transformed and original skinning %) at different combine settings. Data are from an SRUC trial site in Midlothian trial site in 2014.

(a) ANOVA table.

Treatment	df	SS	VR	F.pr
Whole plot				
Variety	1	152.79	27.94	0.119
Residual	1	5.468	0.6	
Sub-plot				
Treatment	9	416.42	5.08	0.002
Variety*Treatment	9	41.888	0.51	0.848
Residual	18	164.06		
Total	39	789.82		

(b) Treatment means for variety and combine settings.

Grand mean 9.75

Variety	Quench	Sanette	l.s.d.	
	11.7	7.79	9.39	
Combine setting treatments				
Drum speed (rpm)	Skinning (arcsine)		l.s.d (arcsine)	Skinning (%)
800	5.25		4.48	1.06
1000	5.85			1.31
1200	4.90			0.88
1400	9.77			3.12
1600	11.07			4.12
Concave setting (5 = tightest)				
1	10.73			3.81
2	9.98			3.38
3	12.27			4.56
4	12.70			5.12
5	14.99			6.94

Propino and Westminster, harvests 2015 and 2016

There was no significant effect of combine harvester setting on TGW and no difference in TGW between Propino and Westminster (Table 27). Specific weight increased significantly with an increase in drum speed and concave tightness (Table 28). The level of skinning in Propino was approximately twice that of Westminster (Table 29). Skinning increased significantly with increasing drum speed and concave tightness (Table 29). Changes in skinning for each variety, in each year, with adjustment in drum speed and concave setting are shown in Fig. 6.

Table 27. (a) Analysis of variance for different combine harvester treatments on thousand grain weight (g) in varieties Propino and Westminster and (b) mean TGW different combine settings. Data are from an SRUC trial site in Midlothian trial site in 2015 only.

(a) ANOVA Table

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Variety	1	5.897	5.155	33.04	0.11
Residual	1	0.178		0.05	
Sub-plot					
Treatment	9	23.83	20.832	0.79	0.629
Variety*Treatment	9	22.233		0.74	0.672
Residual	18	60.331			
Total	39	114.392			

(b) Treatment means for variety and combine settings.

Grand mean 54.6

Variety	Propino	Westminster	l.s.d.
	55	54.2	1.7
Combine setting treatments			
Drum speed (rpm)			
800	53.2		2.72
1000	56.1		
1200	54.3		
1400	54		
1600	55.6		
Concave setting (5 = tightest)			
1	54.3		
2	54.5		
3	54.4		
4	54.4		
5	55.2		

Table 28. (a) Analysis of variance for different combine harvester treatments on grain specific weight (kg/hl) in varieties Propino and Westminster at harvest and (b) mean specific weight at different combine settings. Data are from an SRUC trial site in Midlothian in 2015 and 2016.

(a) ANOVA Table

Treatment	df	SS	SS%	VR	F.pr
Whole plot					
Variety	1	53.792	10.709	1.88	0.264
Residual	3	85.711		10.69	
Sub-plot					
Treatment	9	125.35	24.956	5.21	<.001
Variety*Treatment	9	19.115		0.79	0.623
Residual	54	144.348			
Total	79	502.287			

(b) Treatment means for variety and combine settings.

Grand mean 65.2

Variety	Propino	Westminster	l.s.d.
	64.4	66.1	3.8
Combine setting treatments			
Drum speed (rpm)			
800	63.3		1.64
1000	63.4		
1200	65.2		
1400	65.9		
1600	66.1		
Concave setting (5 = tightest)			
1	64		
2	64.9		
3	65.9		
4	66.4		
5	67.2		

Table 29. (a) Analysis of variance for different combine harvester treatments on grain skinning (arcsine transformed from the original % data) in varieties Propino and Westminster and (b) mean grain skinning scores (arcsine transformed and original skinning %) at different combine settings. Data are from an SRUC trial site in Midlothian trial site in 2015 and 2016.

(a) ANOVA Table

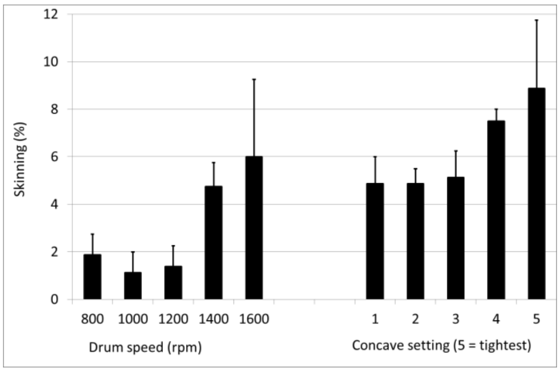
Treatment	df	SS	VR	F.pr
Whole plot				
Variety	1	4357.564	17.02	0.026
Residual	3	767.873	43.3	
Sub-plot				
Treatment	9	881.752	16.57	<.001
Variety*Treatment	9	169.964	3.19	0.004
Residual	54	319.191		
Total	79	9518.469		

(b) Treatment means for variety and combine settings.

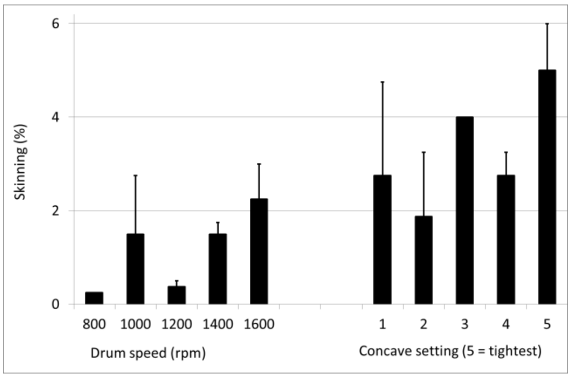
Grand mean 23.13

Variety	Propino	Westminster	l.s.d.	
	30.51	15.75	11.385	
Combine setting treatments				
Drum speed (rpm)	Skinning (ArcSine transformed)	l.s.d.		Skinning %
800	17.4	2.437		10.16
1000	18.69			12
1200	22.18			15.81
1400	23.13			17.38
1600	26.38			21.28
Concave setting (5 = tightest)				
1	20.55			14.88
2	23.17			18.12
3	25.43			20.53
4	26.39			21.72
5	28			24.03

(a)



(b)



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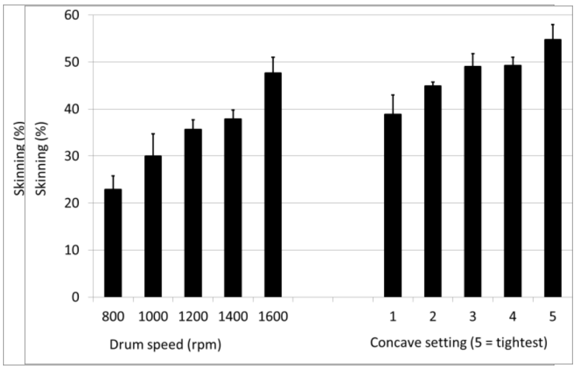
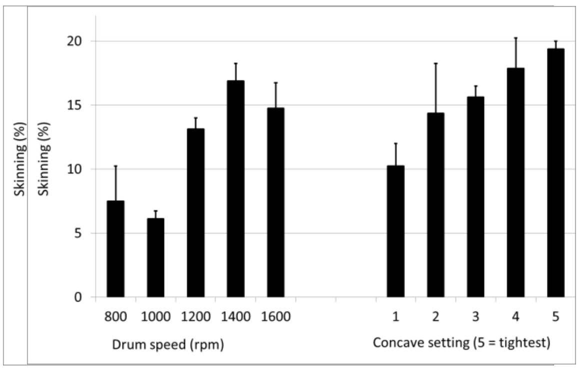


(d)

(e)



(f)

Fig. 6. Effects of combine drum speed and concave setting of grain skinning in (a) Quench and (b) Sanette, harvest 2014, (c) Propino and (d) Westminster, harvest 2015 and (e) Propino and (f) Westminster, harvest 2016. The small bars are the standard error for each mean.

5. Discussion

Variety risk to grain skinning

Demand for home-grown malting barley is increasing, but new varieties with spoilage conditions such as grain skinning can result in rejection at malting intake or inefficiency in grain handling and processing. This has an impact economically on the farming and malting sectors, and downstream processes, including brewing and distilling. Our results confirm that grain skinning is influenced by variety (genetic) and season (environment), but also by crop management. This is consistent with other work that has demonstrated wide variation in skinning among genotypes (Brennan et al. 2017a), but also between seasons, with large effects of growing site conditions (Psota et al. 2011). At present the most skinning resistant varieties are not commercial choices for malting uses. Indeed, most current brewing and distilling varieties have moderate to high risk of grain skinning; with the market leaders Propino and Concerto being particularly vulnerable.

Variation in grain size (TGW) or specific weight, as influenced by variety or agronomic treatment, does not appear to be associated with skinning. This is consistent with our work funded by BBSRC CIRC that indicated how skinning was not associated with variation in grain weight among varieties (Brennan et al 2017a). It remains to be established if large seasonal differences in grain filling or specific weight have any direct link to skinning via changes in husk and caryopsis dimensions (see below). Potential links between skinning and other grain quality traits such as gape, heading date and grain size have been reported elsewhere (Rajasekaran et al. 2004). In commercial bulks, it is possible that a positive relationship between grain weight and skinning could be a consequence of skinned grain contributing to higher mass within the bulk.

Even in years with low levels of skinning, there are likely to be rejections of grain bulks at the maltings because of high susceptibility in some varieties. This is of serious concern among growers and maltsters as the industry continues to rely on a few high yielding barley varieties that have high skinning risk. Evidence of a significant genetic influence on skinning is encouraging for plant breeding as this could underpin the development of new barley varieties with improved husk adhesion and retention, especially under challenging weather conditions that might further increase the risk of poor husk adhesion, or retention. We consider that in the longer term, a reduction in skinning through crop improvement is the best approach to provide a more reliable supply of grain bulks that handle well during combining and post-harvest.

Understanding site and seasonal influences on grain skinning

There has been much debate in the barley sector as to whether or not the occurrence of grain skinning is influenced by seasonal weather patterns that affect grain growth and development. Even in seasons when grain skinning is just a few per cent, nationally there is likely to be rejection of bulks in high risk varieties, as was evident in central Scotland in 2015, and across the UK in 2012. In years when skinning is more than a few per cent, widespread loss of the domestic malting crop can lead to increased barley imports.

Anecdotal evidence from field observations and the malting industry in the UK and Germany suggest that some weather patterns (changes in air humidity or intermittent wet and dry weather) may increase the risk of skinning. This is supported by much earlier work of Hamachi et al. (1989, 1990) who observed that husk growth was strongly affected by environmental conditions, with poor husk development linked to shading or low temperature combined with excess soil moisture. Two reports from Germany (Zimmerman, 1998; Muller and Schildbach, 1998) suggested that both husk and grain (kernel) splitting were present at high levels caused by repeated exposure to heavy rain followed immediately by hot dry weather. From this earlier work, we developed a glasshouse controlled misting environment to create intermittent wetting and drying during grain filling and maturation (Brennan et al. 2017a). Our misting treatment significantly increased skinning, compared to a non-misting treatment.

We are not yet in a position to explain how temperature, solar radiation or moisture might impact directly on skinning. A key question to address is does the weather influence skinning during the husk adhesion process or through changes in grain growth and development that affect husk adhesion or retention? We propose that weather conditions during key phases of husk adhesion (between late milk and early dough stage) and husk retention (between hard dough to harvest ripe stage) need to be examined in more detail. Supported by data from our field trials comparing different harvest dates, we hypothesise that slow and prolonged grain maturation (in late harvested crops), especially under more variable pre-harvest weather, weakens husk retention and increases skinning during combining, or post-harvest handling.

It has suggested that a mismatch in husk and/or caryopsis growth could influence the quality of husk adhesion (Hoad et al. 2016; Rajasekaran et al., 2004). However, this view was not supported by our most recent work in which the quality of husk adhesion (in plants grown under different temperatures) was not linked to incompatibility in husk and caryopsis growth (Brennan et al. 2017b). Furthermore, variation in skinning among more than 200 varieties was not correlated with differences in the size or weights of grain components (Brennan et al. 2017a).

Although the results from our agronomy trials (in this report) provide no evidence for relationships between grain weight, specific weight or screenings and skinning, it is evident that in some seasons, grain skinning may coincide with weather-induced changes in grain growth and development. For example, many spring barley crops from harvest 2012 had high levels of skinning. 2012 was a year of low radiation levels causing poor grain filling nationally, with a reduced grain size (dimensions and weight) and specific weight. In our agronomy trials (in 2012 and 2013), we observed that increased levels skinning after a late harvest was accompanied by reduced grain size (TGW) and specific weight, and increased screenings.

Understanding agronomic influences on grain skinning

Crop protection inputs such as fungicides or PGRs could potentially affect skinning through direct effects on the quality of husk adhesion, or through indirect effects on grain growth and development. However, in this study, there was no evidence to link different fungicide programmes or plant growth regulator treatments to variation in grain skinning. Indeed, significant effects of fungicides on grain yield, grain size and screenings, did not relate to any changes in skinning risk (Fig. 5). We conclude that routine agronomy does not influence skinning risk and that applications of crop protection inputs should not be adjusted as a means to control the condition.

The effects of nitrogen fertiliser on grain skinning were inconclusive. In one trial, there was a very small, but significant, effect of nitrogen fertiliser on skinning (20.4% versus 19.5%). At this stage, we provide no evidence for adjusting routine nitrogen fertiliser inputs to control skinning.

The severity of grain skinning in barley has been shown to be influenced by crop harvesting and handling (Olkku et al. 2005) as well as the environment (Aidun et al. 1990; Psota et al. 2011). Possible effects of crop handling, and especially combine settings, on husk adhesion has been a subject of much discussion among growers. Our work on different combine harvester settings support the observation from Olkku et al. (2005) that mechanical impact is required to cause husks to become detached. Our work indicates that skinning severity is strongly linked to changes in combine settings, with faster or coarser settings increasing the risk. Olkku et al. (2005) also showed that continued mechanical impact, from harvest and during the malting process, increased skinning.

Our ongoing research (e.g. Okoro P *pers. comm.*) suggests that the amount of skinning may be influenced by grain moisture content at harvest and moisture changes during subsequent handling and processing. As moisture content is reduced grains may become more brittle and husk susceptibility to mechanical damage is increased, as reported in Olkku et al. (2005). We are currently attempting to quantify this in our own tests on high risk varieties.

Protocols for field screening and assessing skinning in variety trials

Grain skinning can be assessed in different ways, but is typically based on the proportion of grains that have lost an area of husk above a chosen threshold. Assessing grain skinning is subjective as there is currently no commercially available means of quantitatively measuring the condition. Skinning can occur across any part of the grain and range from a few percent of the husk lost to complete husk detachment.

Our assessment of grain skinning was done according to an in-house protocol developed with the Institute of Brewing and Distilling (Scottish Micro-malting Group), where grains were considered intact if husk loss was less than 20% by area. Grains with 20% or more husk loss were considered skinned. Good consensus can be achieved using a threshold approach (Olkku et al. 2005) and our view is that four replicated sub-samples of 100 grains provide a reliable visual assessment.

Our method of scoring grain skinning is very precise but time-consuming, typically taking 20 minutes per sample (based on assessing 3-4 subsamples of 100 grains). Our recent research has identified a need for a more accurate and rapid measure of grain skinning to support barley evaluation. The ability to screen grain samples using image analysis to support breeding programmes, assess candidate varieties during barley testing and evaluate grain bulks at maltsters' intake would be a significant step forward for the cereals sector. Such high throughput grain assessment requires the development and testing of an image analysis system. Research is needed to establish how surface characteristics in grains with different levels of husk adhesion can be differentiated using methods such as multispectral imaging.

6. References

Agu RC, Devenny DL, Tillett IJL and Palmer GH 2002. Malting performance or normal huskless and acid dehusked barley samples. Journal of the Institute of Brewing, 108(2); 215-220.

Agu RC, Bringhurst TA and Brosnan JM. 2008. Performance of husked, acid dehusked and hull-less barley and malt in relation to alcohol production. Journal of the Institute of Brewing, 114(1): 62-68.

Aidun VL, Harvey BL and Rossagel BG. 1990. Heritability and genetic advance of hull peeling in two-row barley. Canadian Journal of Plant Science, 70: 481–485.

Bryce JH, Goodfellow V, Agu RC, Brosnan JM, Bringhurst TA and Jack FA, 2010. Effect of different steeping conditions on endosperm modification and quality of distilling malt. Journal of the Institute of Brewing, 116(2): 125–133.

Brennan M, Topp CFE, and Hoad SP. 2017a. Variation in grain skinning among spring barley varieties induced by a controlled environment misting screen. The Journal of Agricultural Science, 155: 317-325.

Brennan M, Shepherd T, Mitchell S, Topp CFE and Hoad SP. 2017b. Husk to caryopsis adhesion in barley is influenced by pre- and post-anthesis temperatures through changes in a cuticular cementing layer on the caryopsis. BMC Plant Biology, 17 (1): 169-188.

Hamachi Y, Furusho M and Yoshida T. 1989. Husk development and the cause of under development of husks in malting. Japan Journal of Crop Science, 58: 507-512.

Hamachi Y, Yoshino M, Furusho M and Yoshida T. 1990. Husk size and underdevelopment of husks under excess soil moisture condition in malting barley. Japan Journal of Crop Science, 59: 667-671.

Hoad SP, Brennan M, Wilson GW and Cochrane PM. 2016. Hull to caryopsis adhesion and grain skinning in malting barley: Identification of key growth stages in the adhesion process. Journal of Cereal Science, 68: 8-15.

Mitchell FS, Caldwell F and Hampsong G. 1958. Influence of enclosing the protective tissues on the metabolism of barley grain. Nature, 181: 1270-1271.

Muller C and Schildbach R. 1998. Splitting in malting barleys of the 1997 crop. Brauwelt, 138(6): 220-221.

Olkku J, Kotaviita, E, Salmenkalli-Marttila M, Sweins H and Home S. 2005. Connection between structure and quality of barley husk. Journal of the American Society of Brewing Chemists 63: 17–22.

Psota V, Lukšíčková E, Ehrenbergerová J and Hartmann J. 2011. The effect of the genotype and environment on damage of barley grains (Hordeum vulgare L.). Cereal Research Communications, 39: 246-256.

Rajasekaran P, Thomas WTB, Wilson A, Lawrence P, Young G and Ellis RP. 2004. Genetic control over grain damage in a spring barley mapping population. Plant Breeding, 123: 17–23.

Roumeliotis S, Collins HM, Logue SJ, Willsmore KL, Jefferies SP and Barr AR. 1999. Implications of thin husk in barley. Australian Barley Technical Symposium. The University of Adelaide, Australia. http://www.regional.org.au/au/abts/1999/ roumeliotis.htm

Roumeliotis S, Logue SJ, Hunt C and Barr AR. 2001. Pre-release characterisation of the malting profile of WI-3102. http://regional.org.au/au/abts/2001/t4/roumelioti.htm

Zimmerman H. 1998. Kernel splitting - A new risk in malting barley production. Brauwelt, 138(6): 190-191, 194 and 207-209.

7. Appendix 1

SRUC and MMG Protocol for Assessing Grain Skinning in Malting Barley

Intact barley grain

Barley grains have an adherent husk which is composed of two parts from the flower, the palea and the lemma. The palea covers the ventral side of the grain which is characterised by a central crease and the lemma covers the dorsal side. In most grains, the lemma overlaps the palea along the sides of the grain. Several layers of tissues (pericarp, testa and aleurone) separate the husk from the endosperm, which comprises about 80 % of the mature grain. Immediately beneath the husk lies the pericarp or ovary wall, which protects and supports the growing endosperm and embryo. The caryopsis (or kernel) is the term used to describe all the tissues beneath the husk, including the endosperm. As the grain matures, the palea and lemma become cemented to the pericarp by “glue” that is secreted from the pericarp. From about two weeks after anthesis, the husk becomes very difficult to remove from the caryopsis.

Skinning

Skinning is a loss of the husk as a result of poor grip between the husk and pericarp. Skinning is influenced by grain moisture content and the amount of abrasion to the grain e.g. during harvesting and subsequent handling. Skinning can occur across any part of the grain ranging from a few percent of the husk lost to complete husk detachment. The threshold for skinning is when <u>20% or more of the entire husk</u> (palea and/or lemma) has failed to adhere to the caryopsis – this is observed as either a detached husk or an absent husk.

Skinning can be further defined as dorsal (removal of the lemma), ventral (removal of the palea) or lateral (removal of a longitudinal strip of the palea and/or lemma). A pearled grain is one in which the entire husk has been removed. Skinning can also occur at the ends of the grain, especially at the distal end when there has been damage caused by removal of the awn.

Scoring procedure

Prior to assessments, grain should be screened using a 2.2 mm or 2.5 mm slotted sieve. From the bulked grain, count 100 grains and score skinned grain as the number of grains from which <u>≥ 20% husk is detached or lost</u>. Repeat for four samples of 100 grains and calculate the mean. This represents the percentage of skinned grain from the bulk. Make a note if in the four replicates there is evidence for skinning being one of the following:

(1) mainly the palea (ventral side)

(2) mainly the lemma (dorsal side)

(3) mainly the ends of grains

(4) mainly whole (pearled) grains

Figure 1 illustrates different levels of skinning, viewed from one side of the grain.

Figure 1. The threshold for skinning is based on the whole grain surface. Grains **1)** to **12)** indicate varying levels of skinning. The shaded area represents the intact husk; the white area is the exposed caryopsis. The threshold for a skinned grain is a 20% loss of husk from the whole grain. In the scheme below, assume that grains **1)** to **6)** are intact on the underside, whilst grains **7)** to **12)** are skinned on the underside. Grains **1)** to **5)** are scored as intact and grains **6)** to **12)** are skinned.