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The Direct-Drilling of Forage Kale (*Brassica oleracea* L.) Cultivars Revisited

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Abstract

Kale (*Brassica oleracea* L.) is grown in Great Britain as an autumn and early winter forage crop for dairy cattle. When a new breeding programme was started at the Scottish Crop Research Institute in 1981, kale was being direct-drilled (June) into killed grass swards after early grazing or a first cut for silage, as well as sown early (May) into ploughed and harrowed ground. Research was done to investigate the possibility of cultivar × sowing method interactions but not published at the time because the results did not affect the conduct of the breeding programme and there were other priorities. Perhaps surprisingly, the results still provide novel and relevant information for the breeding and assessment of new kale cultivars which has not become available from more recent research programmes because of cuts in government funding for such work. Ten forage kale cultivars were assessed for ten yield and quality traits in three trials in different years from both sowing into a seed bed prepared by ploughing and harrowing and by direct-drilling into killed grass. The trials had split-plot designs with four replicates in which sowing methods were the main-plots and cultivars the sub-plots. With one exception, the mean squares for sowing method were larger than those for the year × sowing method interactions, but not always statistically significant. The prepared seed bed resulted in taller plants and more fresh-weight and dry-matter yield despite a lower dry-matter content. It also resulted in a slightly lower organic-matter and digestible organic-matter content in the dry-matter but a higher digestible organic-matter yield, crude protein content and content of S-methylcysteine sulphoxide, the haemolytic anaemia factor. There was no difference for content of thiocyanate ion, a goitrogen. There were no interactions between sowing method and cultivars with the exception of digestible organic-matter yield. Cultivars either had higher or similar yields in the prepared seed bed compared with direct-drilling. Four cultivars had above average yields with both direct-drilling and a prepared seed bed. The overall conclusion was that it is unnecessary to assess differences between kale cultivars and breeding material under both conventional sowing and direct-drilling and that the former is easier to do than the latter in small plots. Nevertheless, direct-drilled trials would provide farmers with additional useful information about the yield and quality of new cultivars, should they choose to grow them this way. In contrast, three years of trials are desirable for assessing cultivars because of year × cultivar interactions, particularly for dry-matter and digestible organic-matter yield.

Keywords: *Conventional Seed Bed; Digestible Organic-Matter Yield; Direct-Drilling; Genotype × Environment Interactions; S-Methylcysteine Sulphoxide; Thiocyanate Ion*

Abbreviations

CP: Crude-Protein; DM: Dry-Matter; DOMD: Digestible Organic-Matter in the Dry-Matter; FW: Fresh-Weight; MS: Mean Square; N: Nitrogen; OM: Organic-Matter; SCN^-: Thiocyanate Ion; SCRI: Scottish Crop Research Institute; SED: Standard Error of the Difference between Two Means; SM: Sowing Method; SMCO: S-methylcysteine sulphoxide

Introduction

In the 1970s there was renewed interest in Great Britain (GB) in kale (*Brassica oleracea* L.) as an autumn and early winter forage crop for dairy cattle. This was partly the result of the introduction of direct-drilling of kale into killed grass swards after early grazing (June) or a first cut for silage. The firmer ground which resulted meant less poaching and cleaner cows and made strip grazing using an electric fence more attractive, at least on well-drained soils. Furthermore, the rapid adoption of the method, particularly on grass farms in the south-west of both England and Scotland, was helped by the advent of agricultural contractors specializing in direct-drilling [1]. Kale was, however, still being sown early (May) into ploughed and harrowed ground on mainly arable farms in the east. Hence when a new forage kale breeding programme was being designed at the Scottish Crop Research Institute (SCRI), the possibility of interactions between cultivars and sowing method, sowing date, plant spacing and harvest date was an issue.

The effects of cultivar, sowing date (30 May or 25 June) and plant spacing (6.25 cm or 12.5 cm) on yield and quality were investigated in one experiment [2] and the effects of cultivar and harvest date (mid-September to mid-March) on chemical composition and digestibility in another experiment [3], both experiments being done in 1979. There were no statistically significant interactions between cultivars and spacings, and those between cultivars and sowing dates did not appear to pose serious problems for the assessment of cultivars, although the cultivar differences were larger from the earlier sowing. Likewise, cultivar by harvest date interactions for the same cultivars were not a serious problem, and data from the November harvest showed a satisfactory discrimination between cultivars for all nutritional characteristics. Further insights into genotype × environment interactions for yield and digestibility came from 12 trials which compared two potential new cultivars with five control cultivars and involved five sites, 2 years (1979 and 1980) and a range of sowing and harvest dates [4]. All of these results informed the conduct of the new programme which was started in 1981 with the aim of producing a general-purpose marrow-stem kale (*Brassica oleracea* var. *acephala* L.) suitable for feeding dairy cattle during autumn and early winter. It was successfully completed in 2004 when cultivar Grampian was granted Plant Breeders' Rights [5], a cultivar that is still being grown today.

Assessment of genotypes during the breeding programme was done in replicated yield trials sown into conventionally prepared seed beds on ploughed and harrowed ground between 12 and 26 May and harvested between 25 October and 12 December. However, by the start of the programme, kale was increasingly being direct-drilled into killed grass swards in mid-June. Hence once a direct-drill suitable for small-plots was found, a trial was done in 1982 to investigate cultivar × sowing method interactions and then repeated in 1984 and 1985 after the breeding programme had relocated from Edinburgh to Dundee. It was concluded that direct-drilling was unnecessary for assessing breeding material, and the results were not published apart from a preliminary report by Bradshaw [6] on the 1982 trial. However, some of the cultivars included in the trials are still important ones today, farmers still need advice on cultivars and sowing methods, and there is a need for new cultivars. Hence the results provide novel and relevant information for the breeding and assessment of new cultivars which has not become available from more recent research programmes because of cuts in government funding for such work: the breeding is now done by commercial companies who also provide advice to farmers.

Materials and Methods

Cultivars

The cultivars were chosen to cover a range of types of forage kale: Bittern (a winter hardy triple-cross hybrid between marrow-stem kale and Brussels sprouts), Condor, Maris Kestrel and Merlin (triple-cross hybrid marrow-stem kales), Canson (dwarf winter hardy thousand-head kale), Giganta, Midas and Vulcan (traditional tall marrow-stem kales), Proteor (thin-stemmed French marrow-stem kale) and SCRI KB21, a potential cultivar from the SCRI breeding programme described by Bradshaw and Mackay [7]. The seed used was graded 2.5 - 1.75 mm.

Trial designs

In each of the three years, 1982, 1984 and 1985, the trial had a split-plot design with four replicates in which the main-plots were either prepared seed beds or killed grass and the sub-plots were the cultivars. All sub-plots were 6 m long. The end plants were removed before harvest for a more accurate assessment of yield.

Trial sites and procedures

The trial sites were in the East of Scotland at the Murrays Farm, Pathhead near Edinburgh (1982) and Mylnefield, Invergowrie near Dundee (1984 and 1985). Rainfall recorded at the on-farm weather stations from the beginning of June to the end of November was 409, 471 and 486 mm for the three years, respectively. All sites were grass leys. The grass was cut and lifted in May each year and the trial area marked out. Half of the main-plots were left for direct-drilling whereas the other half were ploughed and a seed bed prepared with a rotary harrow. Trifluralin (Treflan) at 2.34 l/ha was incorporated into the seed bed before sowing for weed control. In the main-plots for direct-drilling, paraquat (Gramoxone) was used to kill the remaining grass sward with an application of 5.62 l/ha in 91 l of water on 4 June 1982, 24 May 1984 and 28 May 1985 followed by a second half-rate application in 1982 (15 June) and 1985 (4 June). Fertilizer granules were applied to the surface of the whole trial area to supply 194, 97, 97 kg/ha, respectively, of N, P_2O_5, K_2O. The direct-drilling was done on 21 June 1982, 7 June 1984 and 17 June 1985, followed by the seed bed sowing three, one and two days later, respectively.

The direct drilling was done with a 6-row Gibbs direct drill [1] with hardened coulter points that had proved suitable for small plot work. The distance between rows was fixed at 30 cm and like all direct drills then available, it was not a precision drill. Metaldehyde mini slug pellets (16 kg/ha) were applied with a Horstine applicator to the slots at drilling and afterwards the plots were rolled to close the slots. The seed bed plots were sown with a Webb precision drill set up for five-rows with 50 cm between rows and 5 cm seed spacing within rows (6.25 cm in 1982). A PTO-driven vacuum pump was used to clean the hoppers of each drill at the end of each plot. After drilling/sowing, one or two applications of chlorpyrifos (Dursban 48E) at 1.5 l/ha were used to control cabbage root fly.

Plant height (Height) of each sub-plot (canopy top as judged by eye) was measured after the period of rapid stem growth, on 26 November 1982, 17 October 1984 and 24 October 1985. The trials were harvested in 1982 (1 to 7 December) and 1985 (11 and 12 November) row by row, with a modified Mais-prinz forage harvester which cut the plants just above ground level, chopped them, and deposited the chopped material into a box attached to a Statimeter weighing device. The fresh-weight (FW) yield was recorded for the centre rows, four for the direct drilled sub-plots and three for the seed bed ones. In 1984 a Hege211B forage harvester was used to cut and weigh the centre rows of each sub-plot (11 and 12 December) which were then chopped using a shredder (Mighty Mac). Two representative chopped samples were taken from each sub-plot. One was oven-dried for 18 h at 80 °C to determine dry-matter (DM) content and hence dry-matter yield of each sub-plot. The other was stored in a cold room at -20 °C until freeze-dried for chemical analyses.

Chemical analyses

The oven-dried samples were milled through a 1 mm sieve in a hammer mill prior to analysis. Organic-matter (OM) content was determined by ashing in a muffle furnace. The digestible organic-matter in the dry-matter (DOMD) was determined using the cellulase method for brassicas as described by Allison and Borzucki [8]. Yield of digestible organic-matter was calculated for each sub-plot. Crude-protein (CP) content was determined by predicting the nitrogen (N) content on a fixed wavelength Technicon 'InfraAlyzer' as described by Allison., *et al* [9]. Each year a set of samples covering the range of predicted values was checked by the Kjeldahl method and adjustments made to the predicted values if necessary (CP = 6.25 × N). OM, DOMD and CP contents were expressed as a percentage of the DM.

The freeze-dried samples were milled through a 1 mm sieve in a hammer mill and then stored in plastic jars with screw-on caps in a deep freeze until they were analysed. The S-methylcysteine sulphoxide (SMCO) determinations were done using the method developed by Gosden [10], but the chromatographic column was removed from the analytical system so that a unit of 10 columns could be used [11]. The thiocyanate ion (SCN^-) determinations were done using the automated procedure of Gosden [12].

Statistical analyses

Appropriate analyses of variance were done for a factorial experiment with a split-plot design, repeated with different randomizations over years, resulting in three sources of residual variation. Years and replicates within years were regarded as random effects whereas sowing methods (SM) and cultivars were treated as fixed effects. Hence the main effects (Year, SM and Cultivar) and their interactions were tested for significance against the appropriate residual or their interaction with years (Year × SM, Year × Cultivar and Year × SM × Cultivar) when the latter was significant. Components of variance of interest were estimated from the appropriate mean squares. The standard error of the difference between two means (SED) was estimated as $(2\times MS/n)^{½}$ where MS is the Mean Square for the appropriate residual or interaction with years (when significant) and *n* is the number of sub-plots contributing to each of the means being compared (120 for SM, 24 for Cultivar, 12 for Cultivar within SM and 8 for Cultivar within Year).

Results

The results of the analyses of variance are shown in table 1. There were statistically significant differences between years for all traits except OM%. However, as no two years are alike, the differences are not that interesting in the context of this paper and are not presented.

Variation	Degrees Freedom	Height	FW yield	DM%	DM yield	OM%
Year	2	31549***	8942***	226.94***	57.56***	8.63^{NS}
Residual	9	131	59	0.33	1.05	2.74
SM	1	21870^{NS}	4842^{NS}	178.40^{NS}	14.94^{NS}	54.24***
Year × SM	2	1196**	905***	15.98**	7.95*	5.23^{NS}
Residual	9	80	46	1.07	1.09	1.68
Cultivar	9	1130***	367*	13.92***	3.20^{NS}	4.50^{NS}
Year × Cultivar	18	100*	105***	0.54^{NS}	1.94***	2.18***
SM × Cultivar	9	85^{NS}	38^{NS}	0.52^{NS}	0.89^{NS}	0.38^{NS}
Year × SM × Cultivar	18	24^{NS}	25^{NS}	0.54^{NS}	0.37^{NS}	0.93*
Residual	162	52	29	0.38	0.53	0.57
Variation	**Degrees Freedom**	**DOMD%**	**DOMD yield**	**CP%**	**SMCO**	**SCN$^-$**
Year	2	376.4***	23.14***	2813.5***	404.3***	19818.9***
Residual	9	9.9	0.57	1.7	8.9	38.8
SM	1	26.4*	7.33^{NS}	643.4***	177.7^{NS}	0.0^{NS}
Year × SM	2	6.3^{NS}	4.48*	0.5^{NS}	50.9**	556.8***
Residual	9	2.9	0.67	2.6	3.4	26.9
Cultivar	9	16.2***	1.72^{NS}	10.2*	19.4***	737.9***
Year × Cultivar	18	3.6^{NS}	1.22***	5.3**	3.3***	54.8***
SM × Cultivar	9	3.3^{NS}	0.64**	2.1^{NS}	0.5^{NS}	5.4^{NS}
Year × SM × Cultivar	18	3.2^{NS}	0.24^{NS}	1.8^{NS}	1.3^{NS}	14.3**
Residual	162	2.8	0.32	2.4	1.3	6.1

Table 1: *Mean squares from analysis of variance and levels of significance for sources of variation for ten traits where SM is variation due to difference between direct-drilling and prepared seed bed.*

*NS: P > 0.05; *: P 0.05-0.01; **: P 0.01-0.001; ***: P < 0.001.*

The design of the experiment means that there are just one and two degrees of freedom respectively for SM and the Year × SM interaction. Hence perhaps not surprisingly, for all traits either the SM item or the Year × SM item was statistically significant, but not both. However, with the exception of SCN^-, the mean squares for SM were larger than those for the Year × SM interaction. The differences between a prepared seed bed and direct-drilling are shown for the ten traits in table 2, averaged across years and cultivars. The prepared seed bed resulted in taller plants and higher FW and DM yields despite a lower DM%. It also resulted in a slightly lower OM% and DOMD% but a higher DOMD yield, CP% and SMCO content.

	Height cm	**FW yield t/ha**	**DM%**	**DM yield t/ha**	**OM%**
Direct-drilled	68.4	43.5	14.68	6.19	90.14
Seed bed	87.5	52.5	12.96	6.69	89.19
SED	4.46	3.88	0.516	0.364	0.167
	DOMD%	**DOMD yield t/ha**	**CP%**	**SMCO g/kg DM**	**SCN^- mg/100 g DM**
Direct-drilled	78.68	4.85	17.40	7.45	27.1
Seed bed	78.01	5.20	20.67	9.17	27.1
SED	0.222	0.273	0.210	0.921	3.05

Table 2: *Comparison of prepared seed bed with direct-drilling for ten traits.*

Table 1 also shows that for DM% and DOMD% there were no interactions between Cultivar and Year, Cultivar and SM, and Cultivar, Year and SM. For all of the other traits there were Year × Cultivar interactions. The ratio of the components of variance for Year × Cultivar and Cultivar (YC/C) gives an indication of the relative importance of the interactions (Table 3). They were particularly large for DOMD and DM yield, followed by OM%, CP% and FW yield. The interactions for FW yield were the main contributor to those for DM and DOMD yield as there were no statistically significant interactions for DM% and DOMD%. In contrast, the interactions were relatively small for SMCO, SCN^-, DOMD%, Height and DM%.

	Height cm	**FW yield t/ha**	**DM%**	**DM yield t/ha**	**OM%**
Bittern	74.4	43.2	15.25	6.40	90.18
Canson	69.2	41.3	13.93	5.62	90.28
Condor	77.4	49.5	13.71	6.58	89.38
Giganta	83.5	50.0	12.73	6.19	89.06
Maris Kestrel	68.9	48.3	13.50	6.33	89.51
Merlin	76.9	50.3	13.64	6.72	89.22
Midas	84.1	46.5	14.18	6.40	89.95
Proteor	81.5	53.8	13.45	6.99	89.71
Vulcan	90.1	51.8	13.02	6.63	89.30
SCRI KB21	73.5	45.1	14.78	6.54	90.07
Mean	78.0	48.0	13.82	6.44	89.67
SED	2.88	2.96	0.179	0.402	0.426
YC/C	0.139	0.871	0.034	3.343	2.079

	DOMD%	DOMD yield t/ha	CP%	SMCO g/kg DM	SCN^- mg/100 g DM
Bittern	78.81	5.02	18.12	8.02	27.3
Canson	79.11	4.43	20.23	10.69	39.2
Condor	78.70	5.17	18.97	8.00	22.5
Giganta	77.75	4.81	19.86	8.15	21.5
Maris Kestrel	79.66	5.02	19.33	8.66	26.6
Merlin	78.78	5.28	19.35	8.00	23.1
Midas	77.76	4.95	18.69	7.31	25.5
Proteor	77.47	5.40	18.57	7.98	31.0
Vulcan	77.01	5.06	18.59	8.07	22.6
SCRI KB21	78.41	5.10	18.63	8.20	32.0
Mean	78.35	5.02	19.03	8.31	27.11
SED	0.484	0.319	0.663	0.523	2.14
YC/C	0.181	5.356	1.750	0.366	0.214

Table 3: *Comparison of cultivars for ten traits, averaged over 3 years and two sowing methods where YC and C are the components of variance for Year × Cultivar interactions and Cultivars, respectively.*

With the exception of DOMD yield, there were no SM × Cultivar interactions. Furthermore, with the exceptions of OM% and SCN^-, there were also no Year × SM × Cultivar interactions. The differences between cultivars are shown for the ten traits in table 3, averaged across years and SM. The highest DM and DOMD yields were in two medium height cultivars, Merlin and Proteor. The highest DM% was in cultivar Bittern, the winter hardy kale × Brussels sprouts hybrid. The short-stemmed cultivar Maris Kestrel had the highest DOMD%. The dwarf winter hardy thousand-head kale Canson had the highest CP% but also the highest SMCO and SCN^- contents along with the lowest yields. Midas had the lowest SMCO content and Giganta the lowest SCN^- content, both cultivars being traditional tall marrow-stem kales.

The SM × Cultivar interactions for DOMD yield are shown in table 4. Cultivars either had higher or similar yields in the prepared seed bed compared with direct-drilling, with the largest differences shown by Bittern (0.68 t/ha), Maris Kestrel (0.77) and Proteor (0.76). Cultivars Condor, Merlin, Proteor and SCRI KB21 had above average yields with both direct drilling and a prepared seed bed.

	Direct-drilled	Seed bed	Mean	Difference Seed - Direct
Bittern	4.68	5.36	5.02	0.68
Canson	4.27	4.58	4.43	0.31
Condor	4.93	5.40	5.17	0.47
Giganta	4.82	4.79	4.81	-0.02
Maris Kestrel	4.63	5.40	5.02	0.77
Merlin	5.23	5.33	5.28	0.10
Midas	4.89	5.02	4.95	0.12
Proteor	5.02	5.78	5.40	0.76
Vulcan	5.13	5.00	5.06	-0.13
SCRI KB21	4.89	5.32	5.10	0.43
Mean	4.85	5.20	5.02	0.35
SED	0.230	0.230	0.319	

Table 4: *DOMD yields (t/ha) of ten cultivars in two sowing methods, averaged over 3 years.*

The Year × Cultivar interactions for DOMD yield are shown in table 5. The average range over the three years was 0.97 t/ha. Cultivar Vulcan had the smallest range, 0.18 t/ha, and cultivar Midas the largest range, 2.10 t/ha. There were changes of ranking with Vulcan best in 1982 but 9th in 1985, whereas Midas was best in 1985 and 9th in 1982.

	1982	1984	1985	Mean
Bittern	4.43	5.15	5.48	5.02
Canson	3.57	4.51	5.20	4.43
Condor	4.85	5.31	5.35	5.17
Giganta	4.63	5.15	4.64	4.81
Maris Kestrel	3.97	5.42	5.66	5.02
Merlin	4.73	5.42	5.70	5.28
Midas	3.80	5.16	5.90	4.95
Proteor	4.58	6.07	5.55	5.40
Vulcan	5.01	5.18	5.00	5.06
SCRI KB21	4.48	5.62	5.21	5.10
Mean	4.40	5.30	5.37	5.02
SED	0.282	0.282	0.282	0.319

Table 5: *DOMD yields (t/ha) of ten cultivars in three years, averaged over two sowing methods.*

The components of variance for DOMD yield were 0.0210 for Cultivar [(1.7221 - 1.2179)/24], 0.1125 for Year × Cultivar [(1.2179 - 0.3176)/8], 0.0268 for SM × Cultivar [(0.6389 - 0.3176)/12], 0 for Year × SM × Cultivar and 0.3176 for their residual. These figures are another way of revealing the large Year × Cultivar interactions and smaller SM × Cultivar interactions.

Discussion

The experiment demonstrated that it is possible to direct drill the small plots used by breeders to assess a large number of families/lines with relatively small quantities of seed. It had proved relatively easy to modify commercially available precision drills for small plots in traditionally prepared seed beds (ploughed and harrowed). At SCRI a Webb precision drill was set up for five-rows with 50 cm between rows and the desired seed spacing within rows. A PTO-driven vacuum pump was used to clean the hoppers of each drill at the end of each plot. In contrast, most of the commercially available direct-drills used by contractors (e.g. the Bettinson and Moore) were too large and required too much seed for small plots. The exception was the 6-row Gibbs direct drill [1] which only required between three and four times as much seed as a precision drill (6 × 3g seed compared with 5 × 1g seed per plot) [4]. Hence it was possible to investigate genotype by sowing method interactions and to ask whether or not it is necessary to breed kale cultivars specifically adapted to direct drilling. The conclusion in 1986 from the results presented in this paper was that direct-drilling was unnecessary for assessing breeding material, which therefore continued to be done in traditionally prepared seed beds. Out of ten traits, there were only statistically significant sowing method × cultivar interactions for DOMD yield and these did not result in major changes in ranking of cultivars, despite the component of variance for the interaction being slightly larger than the component for cultivars (0.0268 compared with 0.0210). Hence the easier method of sowing into a seed bed was preferred. Nevertheless, one can argue that direct drilled trials of new cultivars would provide farmers with some useful information, including assurances that weaknesses would not appear when the cultivars are grown this way.

The ten traits studied are still the most important ones to consider when assessing the yield and quality of forage kale cultivars. The overall means for these traits and the differences between cultivars were much as expected from previous work [2,3], with the exception of a higher mean for DOMD% (78.4% compared with 70.1% and 71.3%, respectively). In contrast, the differences between direct-drilling and sowing into a seed-bed were new results. The prepared seed bed resulted in taller plants and more fresh-weight and dry-matter yield despite a lower dry-matter content. It also resulted in a slightly lower organic-matter and digestible organic-matter content, but a higher digestible organic-matter yield, crude protein content and levels of S-methylcysteine sulphoxide, the haemolytic anaemia factor which can cause kale poisoning in ruminants [13,14]. No difference was found for the concentration of thiocyanate ion, a goitrogen released from the indolyl glucosinolates present in kale [15]. However, as there were interactions of sowing method with years for seven out of the ten traits, it is premature to offer explanations for the differences. More research is required and should prove valuable to farmers, particularly as it has been lacking since the initial enthusiasm for direct-drilled kale in Great Britain in the 1970s [1]. There was also interest in the United States in using conservation tillage to reintroduce forage brassica crops for livestock production, with trials being done in Pennsylvania over the period 1976-1981 [16]. One more recent example is a New Zealand study (43°36'S, 171°35'E) by Ruiter and Edwards [17]. They used the tall marrow-stem kale cultivar Gruner to compare sowing method and fertilizer level, the sowing methods being direct-drilled, cultivated with seed drilled, and cultivated with seed broadcast. They concluded that dry-matter yields, percentage utilization by dairy cattle and costs of production did not appear to be important factors in determining farmers' choice of sowing method.

The 3 years of trials did confirm that year × cultivar interactions need to be taken into account in kale breeding and cultivar assessment. Selection during a breeding programme over a number of generations, and hence years, is likely to be most effective for traits displaying little interaction and least effective for traits with large interactions and changes in ranking. The traits least affected by year × cultivar interactions were DM%, Height, DOMD%, SCN^- and SMCO, and those moderately affected were FW yield, CP% and OM%, with DM and DOMD yield the most affected. Of the traits assessed by Bradshaw., *et al.* [4] for two potential cultivars and five controls, DM% and Height were also the least affected by interactions, with FW yield moderately affected and DM and DOMD yield again among those most affected; but the interactions for OM% and DOMD% were also relatively large compared with the differences between cultivars. Bradshaw and Mackay [7], in their breeding programme, attributed apparently initially encouraging and then disappointing results in selecting for improved DOMD yield to the presence of genotype by environment interactions. In contrast, effective selection over four generations for lower SCN^- contents, in each of two separate breeding programmes, is further evidence for little genotype by environment interaction in this trait [5,18].

The largest interactions occurred for DOMD yield and this was the trait used in deciding the number of sites and years in official trials of new cultivars in the United Kingdom [19]. Talbot [20] analysed DOMD yield variability of autumn kale in 61 official trials of new cultivars. These covered the sowing years 1971 to 1980 and included 15 cultivars and 8 trial centres, although official trials for a particular new cultivar involved up to eight sites for two years, plus additional trials before recommendations were made to farmers [19]. The overall mean was 5.5 t/ha compared with 5.02 t/ha in the current experiment and the component of variance for plot error (residual) was 0.245 compared with 0.318. The cultivar × centre × year interaction component (0.114) was large and similar in magnitude to the component for cultivars (0.106). In the current experiment the equivalent cultivar × year interaction (years and centres were confounded) component had a similar value (0.113) whereas the cultivar component was much lower (0.021). These results are of help in deciding a practical balance of sites and years to achieve a sufficient number of different environments for making recommendations about new kale cultivars, with three years preferable to just two years.

Conclusion

The overall conclusion is that the common practice of assessing new kale cultivars in yield trials for two or three years at a number of sites (three to eight) is reasonable for a minor crop, and that it is not essential to trial them from direct-drilling to determine their relative characteristics. Likewise, it is reasonable to assess the generations of a breeding programme in conventionally prepared seed-beds in the different environments provided by different years. Furthermore, it is doubtful that a kale can easily be bred that is specifically adapted to direct-drilling. Nevertheless, direct-drilled trials would provide farmers with additional useful information about the yield and quality of new cultivars, should they choose to grow them this way, just as this paper provides information about some currently grown cultivars including Bittern and Maris Kestrel.

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Conflict of Interest

The author declares no conflict of interest.

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