SPROUTING RADISH (*Raphanus sativus* L.) SEED PRODUCTION EFFECTS OF CROP MANIPULATION

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ABSTRACT

Sprouting radish (*Raphanus sativus* L.) seed production is a possible alternative for New Zealand cropping farmers, but little is known of the crop's agronomic requirements. A spring-sown field trial in 1984 at Palmerston North, New Zealand, examined the effects of plant population and crop manipulation on seed production. Plant population differences were achieved by sowing at 5, 10 and 15 kg ha^{-1} in 30 cm rows. Crop manipulation included topping at first anthesis, application of the growth retardant paclobutrazol (PP333) prior to stem elongation, and sowing in 15 cm rows, all at a sowing rate of 10 kg ha^{-1}.

Four distinct developmental phases were observed, and the phenology of the crop recorded. No treatment (sowing rate, row spacing) differences were observed, but PP333 application suppressed elongation of the main stem and removed apical dominance, allowing similar development of the terminal raceme and several axillary racemes.

Harvested seed yield (203-220 g m^2) did not differ between sowing rates, was reduced 17% by topping, increased 32% by sowing in 15 cm rows and was not increased by PP333 application. However, PP333 treated plots had a potential seed yield 121 g m^{-2} greater than that of other treatments because more pods were retained per plant. The failure to increase actual seed yield following the PP333 treatment occurred because not all seed was removed from the pods during threshing.

The effects of crop manipulation on seed yield are discussed. However, irrespective of treatment, over 33% of all seed harvested was unsuitable for sprouting because the seed coat was cracked or the seed was split. Methods for harvesting quality seed require investigation.

***Additional Key Words:** topping, paclobutrazol, sowing rate, seed yield, threshing, seed coat damage*

INTRODUCTION

Sprouting radish (*Raphanus sativus* L.) has recently become a popular food in Japan and the demand for quality seed for sprouting is high; a recent estimate is that the Japanese market would take up to 5,000 tonnes of seed annually (G.C. Stewart, pers. comm.). Current suppliers of seed for this market are South Korea, USA, and more recently, New Zealand. The crop was first grown commercially in New Zealand in the 1982/83 season, and in 1983/84, 278 ha were grown, mostly in Ashburton county. Two hundred tonnes of seed were produced at an average yield of 0.7 t ha^{-1} (K.I. Stevenson, pers. comm.). Although top quality seed has realised up to \$6 kg^{-1}, returns to New Zealand growers were around \$1 kg^{-1} because of quality problems which included slow and uneven germination and cotyledon lesioning.

New Zealand arable farmers are looking for crops to broaden the present narrow production base. If grown successfully, sprouting radish could provide a valuable alternative crop, but information on the production of quality seed is limited. At present, if seed is rejected for sprouting purposes because of low quality, it has no alternative use.

Production problems identified in the first two seasons the crop was grown in New Zealand included uneven flowering and podripening, lodging, pest and disease control, and harvesting techniques and timing (I.C. Harvey and B.J. Davidson, pers. comm.). In 1984/85 a trial at Palmerston North, Manawatu, New Zealand examined the effects of plant population and crop manipulation on the production of sprouting radish seed. In this paper, we describe the effects on crop growth, development and seed yield.

MATERIALS AND METHODS

Raphanus sativus cv. Diakon was sown by cone seeder on 12 September 1984 into a Tokomaru silt loam soil which had been cropped in barley the previous season. The site had a pH of 5.4 and MAF P and K soil test results (Cornforth and Sinclair, 1982) of 16 and 8 respectively. Plots were 2.4 m wide by 12 m long separated by radish 'buffer zones' of 0.5 m between plots and 2.5 m between blocks. Treatments were three sowing rates (5, 10, 15 kg seed ha^{-1} in 30 cm rows) and three crop manipulations (topping at first anthesis, growth retardant and row spacing, all sown at 10 kg seed ha^{-1}, the first two in 30 cm rows and the last in 15 cm rows). A randomised complete block design with four replicates for each treatment was used.

No seedbed fertiliser was applied. Trifluralin at 2 litres product ha^{-1} was used in a pre-emergence application for weed control. 100 kg N ha^{-1} (urea) was applied to all plots on 15 October, and the growth retardant paclobutrazol

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(PP333) applied to one plot per block at 1.0 kg a.i. in 200 litres water ha^{-1} on 17 October. At first flowering (8 November) one plot per block was topped to 15 cm by a rotary mower. Brassica leaf miner (*Scaptomyza* sp.) was controlled by spraying with chlorpyrifos (500 ml product in 200 litres water ha^{-1}) at the end of anthesis (15 December).

Crop development was monitored weekly in the field, and growth analyses were carried out after pod set (17 December) and prior to harvest (18 January), by removing 2 x 0.3 m^2 subsamples from the middle three rows of each plot. Yield components were determined from 15 randomly selected plants per plot.

Plots were covered with 'Netlon' 15 mm synthetic netting positioned 1.5 m above the crop to prevent bird damage from the end of November until final harvest. Pod and seed moisture content (SMC) were monitored every two days by oven drying (ISTA 1976), and the crop was desiccated with diquat (4 litres ha^{-1}) when pod moisture content reached 30%. Seed was harvested (29 January) at 9% SMC from 10.8 m^2 per plot by using a 1.6 m cut combine with the concave nearly touching and a drum speed of 480 rpm. Seed was cleaned using a 'Clipper' bench model seed cleaner and following a purity analysis (ISTA 1976) divided into pure seed with: seed coat intact; seed coat split; seed split; and inert matter. Yield results are expressed at 0% SMC.

RESULTS

Phenology

Four distinctive developmental phases were observed:

1. Vegetative growth — germination, emergence and growth of a rosette of eight to eleven leaves (> 5 mm in length) over a period of five weeks.
2. Stem elongation — growing point visibly reproductive; elongation of the main stem, bearing a terminal inflorescence and with axillary flowering branches differentiated at each node.
3. Flowering — occurred over a six week period. The first flower to open was the lowermost on the terminal raceme. Flowers on a raceme opened in acropetal sequence, and the axillary racemes began flowering in basipetal sequence at intervals of one or two days. Elongation of the stems continued through the early flowering period, and the plants reached a height of 0.75-1.00 m. The terminal raceme carried the largest number of flowers and was in flower over a three and a half week period; individual flowers took five or six days from petal opening until petal drop, which left the pod visible. The lower inflorescences, particularly those beneath the top four nodes had fewer flowers and contributed little to pod set.
4. Pod development — because of the long flowering sequence, the change from flowering to pod development was less marked than the earlier developmental phases. Pods were cylindrical, indehescent with conical beaks, and increased rapidly in length and diameter, reaching full size two weeks after petal fall. Seeds at this time were full sized, consisting largely of liquid endosperm containing a small green embryo and bound by a translucent testa. Maximum dry weight of the seed was reached four weeks from petal fall, at which state the pods were beginning to turn yellow and the seed testa was brown and opaque. Seed moisture content was around 40%. Over the flowering period the lower leaves gradually senesced, so that by early pod development, the pods and stems constituted the major source of photosynthetic tissue, a result also recorded in *Brassica napus* (Tayo and Morgan, 1975).

The observed pattern of crop development is summarised in Table 1, and closely followed that reported

TABLE 1: Phenology of spring sown* sprouting radish, Palmerston North 1984.

Weeks after sowing	Growth Stage	Comments
1	Emergence	
3	Young rosette	First true leaf > 5 mm.
4	Rosette	Rapid development of 8-11 leaves.
5	Reproductive rosette	Growing point visibly reproductive.
7	Main stem elongation	Rapid stem growth to 20-30 cm. Axillary shoots not diverged or elongated.
8	First anthesis	First flowers on terminal raceme of main stem open. Rapid elongation of main stem and axillary branches continues.
11	Peak anthesis	Flower opening occurs acropetally along a raceme and basipetally from the terminal raceme.
14	Anthesis complete	Petal fall on lowermost axillary racemes. Rosette leaves sensesced.
16	Pods reach maximum size	Seed full sized but mainly liquid endosperm tissue, translucent testae.
20	Harvest ripeness	Seed moisture content 10-12%.

* sown 12 September 1984

TABLE 2: The effect of sowing rate and crop manipulation on stem length, broken stems m^{-2} and stem and pod dry matter at final harvest.

	main stem length cm	broken stems m^{-2}	dry matter stem g m^{-2}	dry matter stem g stem^{-1}	dry matter pod g m^{-2}	dry matter pod g pod^{-1}
Sowing rate						
5 kg	86.8	11.6	448.4	29.4	620.4	0.176
10 kg	87.4	14.8	432.4	30.7	628.4	0.159
15 kg	88.1	19.2	424.1	32.2	496.7	0.149
s.e. diff (6 d.f.)	7.1	2.8	18.6	5.1	36.4	0.02
Crop manipulation						
10 kg + topping	68.2	10.4	343.5	34.0	492.6	0.148
10 kg + PP333	58.6	0.6	407.3	38.2	758.2	0.137
10 kg + 15 cm rows	86.6	21.6	499.1	36.9	608.6	0.154
s.e. diff (9 d.f.)[1]	7.5	4.3	26.4	4.8	32.8	0.02

[1] analysis includes 10 kg + 30 cm row data — applies to all Tables.

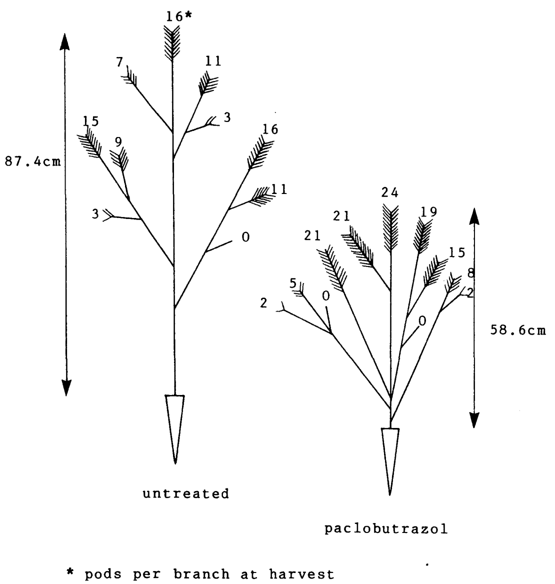

Figure 1: Diagramatic representation of a sprouting radish plant at final harvest.

for *Brassica napus* oil seed crops (Thurling, 1975; Tayo and Morgan, 1975). At the stated time interval 70-80% of plants in a plot were at the growth stage recorded. No treatment (sowing date; row spacing) differences were observed.

Application of PP333 suppressed elongation of the main stem (58.6 cm cf. 87.4 cm, Table 2) and altered plant morphology (Figure 1). Elongation of the flowering racemes still occurred, but the terminal raceme and several axillary racemes were all similar in development, whereas in untreated plants the terminal raceme was dominant in terms of length, number of flowers produced and number of pods developed. PP333 reduced the spread of flowering, as although some flowers were found over the same 6 week period as in untreated plots, a greater percentage of the total flowers opened over a shorter interval (4.5 weeks). Little development of axillary racemes on stem nodes below the fourth or fifth occurred, and more pods were therefore produced at the top of the plant (107 pods on the terminal and first 5 axillary racemes in PP333 treated plants cf. 76 pods on the same racemes in untreated plants — Figure 2).

Lodging

Lodging of plants began during anthesis, and by harvest around 40% of plants in all three sowing rate treatments and the 15 cm row treatment had broken stems and were lodged. PP333 significantly ($P<0.01$) reduced the number of plants with broken stems (Table 2).

Dry matter production

At final harvest there were no significant differences in stem dry matter m^2 or per individual stem between sowing rate treatments, PP333 and 15 cm row spacings (Table 2). Topping the crop reduced total stem dry matter. Pod dry matter m^2 was reduced by topping and the 15 kg sowing rate, but PP333 application significantly ($P<0.01$) increased pod dry matter (Table 2). There were no significant treatment effects on individual pod weights.

Seed yield and components of yield

Harvested seed yield at 203-220 g m^{-2} was similar for all 3 sowing rates (Table 3), and no significant differences were recorded in the number of pods or seeds per unit area. However, as plant population increased (Table 3), yield per plant fell from 11.7 to 6.1 g ($P<0.05$) and the number of pods per plant fell from 117.0 to 70.3 ($P<0.05$) (Table 4). Although the number of seeds per pod also fell (Table 4), differences were not significant.

Topping the crop reduced seed yield by 35 g m^{-2} ($P<0.05$), sowing in 15 cm rows increased seed yield by 65

TABLE 3: The effect of sowing rate and crop manipulation on seed yield and yield components per unit area.

	plants m^{-2}	pods m^{-2}	seeds m^{-2}	seed yield $g\ m^{-2}$ potential[1]	actual[2]	harvest index %
Sowing rate						
5 kg	30.0	3510	21832	352	212	32.9
10 kg	42.5	3952	23277	379	203	35.7
15 kg	47.5	3340	17969	289	220	31.3
s.e. diff (6 d.f.)	5.23	648.3	2468.6	11.8	9.9	6.8
Crop manipulation						
10 kg + topping	47.5	3338	20795	324	168	38.7
10 kg + PP333	47.5	5505	31489	500	222	42.9
10 kg + 15 cm rows	52.5	3940	22103	358	268	32.3
s.e. diff (9 d.f.)	4.89	589.6	2681.7	17.3	12.4	5.1

[1] from growth analysis
[2] cleaned seed, but see Table 5

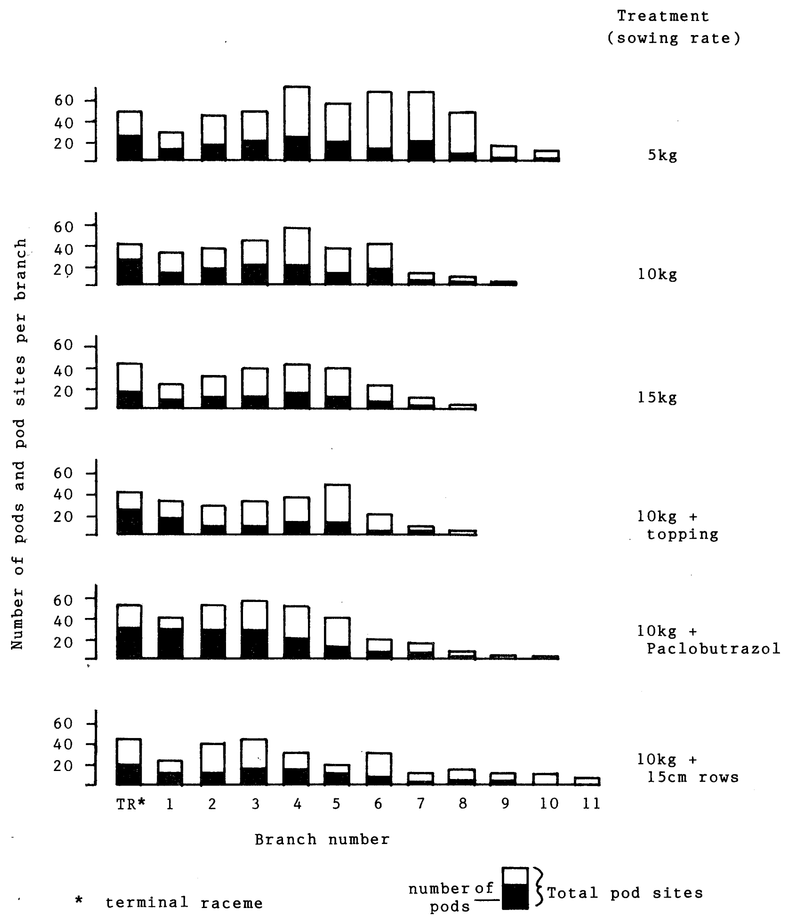

Figure 2: Effect of sowing rate and plant manipulation on total pod sites and number of pods per branch at final harvest.

TABLE 4: **The effect of sowing rate and crop manipulation on individual plant seed yield and yield components.**

	seed yield g $plant^{-1}$	pod $plant^{-1}$	seed pod^{-1}	mean seed weight mg
Sowing rate				
5 kg	11.7	117.0	6.2	16.1
10 kg	8.9	93.0	5.9	16.3
15 kg	6.1	70.3	5.4	16.1
s.e. diff (6 d.f.)	1.01	8.3	0.38	2.12
Crop manipulation				
10 kg + topping	6.8	70.3	6.2	15.6
10 kg + PP333	10.6	115.9	5.7	15.9
10 kg + 15 cm rows	6.8	75.0	5.6	16.2
s.e. diff (9 d.f.)	1.21	7.9	0.46	1.89

TABLE 5: **Seed yield (g m^{-2}) of purity separations from cleaned seed**

	intact seed coat	cracked seedcoat	split seed	inert matter
Sowing rate				
5 kg	131.3	19.4	59.0	2.3
10 kg	131.1	21.0	49.6	1.3
15 kg	137.8	19.9	58.2	4.1
s.e. diff (6 d.f.)	8.4	1.1	4.6	0.32
Crop manipulation				
10 kg + topping	102.9	13.0	51.3	0.8
10 kg + PP333	116.5	17.3	85.2	3.0
10 kg + 15 cm rows	171.6	27.2	66.2	3.0
s.e. diff (9 d.f.)	9.2	0.9	3.2	0.41

g m^{-2} ($P<0.01$), while the yield of plants treated with PP333 did not differ from that of untreated plants (Table 3). PP333 application increased the number of pods per unit area ($P<0.01$) and per plant ($P<0.05$) (Tables 3 and 4), while topping, and sowing in 15 cm rows, reduced the number of pods per plant from 93.0 to 70.3 and 75.0 respectively ($P<0.05$, Table 4). Crop manipulation did not significantly change the number of seeds per pod, and mean seed weight did not differ between treatments (Table 4).

Harvested seed yields were between 90 to 278 g m^{-2} less than potential yields obtained from growth analysis (Table 3). Potential seed yield was significantly decreased at the 15 kg ha^{-1} sowing rate, but increased 121 g m^{-2} ($P<0.01$) by PP333 application, because of a greater number of pods per unit area (Table 3). Harvest index, calculated from the potential seed yield, did not differ significantly between treatments (Table 3) although it was increased from 35.7 to 42.9 by PP333 application.

For all treatments except PP333, around 37% (65-92 g m^{-2}) of harvested seed was considered unsuitable for sprouting because the seedcoat was cracked or the seed was split (Table 5). With PP333, this percentage rose to 47% (105 g m^{-2}), because of an increase in the amount of split seed ($P<0.01$). Variations in the weight of seed in the four purity categories (Table 5) reflect treatment variations in actual seed yield (Table 3), as with the exception of PP333, the percentage of seed within each category did not differ between treatments (Table 5).

DISCUSSION

Yield in sprouting radish is determined primarily by the number of pods, a characteristic of other indeterminate species such as oil-seed rape (Dawkins, 1983) and field beans (Attiya, Field and Hill, 1983). In this experiment, the three seeding rate treatments produced a potential pod number of 10-11,000 m^{-2}, but only 3,300-3,900 (30-38%) survived to become fertile pods. These data are similar to those reported for oil-seed rape (Dawkins and Almond, 1984). Pod number in oil-seed rape may be increased by early sowing (Mendham, Shipway and Scott, 1981) or growth regulator application (Daniels, Scarisbrick, Chapman and Noor Rawi, 1982; Addo-Quaye, Daniels and Scarisbrick, 1985). However, greater pod numbers do not always produce a greater seed yield, because seed numbers per pod may be reduced, and/or pod abortion may increase (Scarisbrick and Daniels, 1984). A canopy with a large number of pods per unit area will result in intense competition for light and/or assimilate between the pods (Dawkins and Almond, 1984). A dense canopy may also shade the lower pods making them less productive.

Dawkins and Almond (1984) discussed the potential for manipulation of the oilseed rape crop and concluded that seed yield may be increased if:

(i) the orientation of the branches was changed so that shading was reduced,

(ii) apical dominance was reduced so that there was a better contribution to yield from the lower branches, or conversely, late formed branches were suppressed so that they would not compete for assimilates with the upper canopy. Making the crop more determinate with a more even maturity within and between branches would also be of considerable practical benefit, a conclusion that applies equally well to sprouting radish.

Topping the sprouting radish crop at first anthesis did not achieve either of these aims. The number of pod bearing branches per plant was decreased from 9.8 to 9.2, and the number of pod sites per plant decreased from 241 to 206. No differences were found in the percentage of pods retained between topped and non-topped plants, but yield was reduced because of the significant reduction in the number of pods per plant.

Application of the growth retardant PP333 increased potential seed yield 121 g m^{-2} (32%), by significantly increasing the number of pods per plant and per unit area. This arose from an increase in the number of pods retained; out of 10,300 potential pods m^{-2}, 5,505 or 53% were retained, compared with 38% for untreated plants. PP333 had previously been shown to reduce seed abortion in perennial ryegrass (Hampton and Hebblethwaite, 1985a) and increase pod retention in field beans (Attiya *et al.*, 1983) and oil-seed rape (Dawkins and Almond, 1984; Addo-Quaye *et al.*, 1985), by changing the partition of assimilates to favour seed rather than stem or vegetative growth (Hampton and Hebblewaite, 1985b). The mechanism by which this occurs has yet to be determined; it is possible that the reduction in stem length in PP333 treated plants at the beginning of pod set increased the competitive ability of the pods for assimilates (Attiya *et al.*, 1983), but this theory was not proven in similar experiments with perennial ryegrass (Hampton and Hebblewaite, 1985a). Addo-Quaye *et al.* (1985) showed that PP333 increased the yield of oil-seed rape by influencing canopy structure (allowing improved light interception in a more efficient crop canopy) and altering assimilate distribution, so that more assimilates were translocated to the reproductive parts of the upper branches, especially the terminal raceme. It is likely that a similar response occurred in sprouting radish, but this has yet to be confirmed.

Lodging, which began prior to the completion of anthesis, was significantly reduced by PP333. The effects of lodging on seed yield of sprouting radish have yet to be determined, but shading of the canopy caused by lodging could reduce the photosynthetic capacity of the crop and hence reduce seed yield. As with oil-seed rape, grazing of seed pods by small birds (Daniels *et al.*, 1982) is encouraged by a lodged canopy which provided a better site for alighting than an upright crop. Lodging also provides a microclimate which encourages the development of fungal pathogens, in particular *Alternaria* and *Sclerotinia* spp (I.C. Harvey, pers. comm.).

The 30 cm row spacing used in this experiment was that in commerical use in Canterbury (C. Lill, pers. comm.). However, seed yield from a 15 cm row spacing was 65 g m^{-2} (32%) greater than that from a 30 cm row spacing. This result followed that found previously for oil-seed rape (Christensen and Drabble, 1984), where decreasing row spacings from 23 cm to 15 cm, and from 15 cm to 7.5 cm increased yields by an average of 11% and 33% respectively. Conversely, Nautiyal and Lal (1982) reported greater seed yield from 60 x 60 cm spacings of transplanted radish plants than 45 x 45 cm spacings.

Although seed yield was increased with the 15 cm row spacing, the potential seed yield did not differ between treatments, and thus actual seed yield differences may have been a factor of harvesting technique rather than any direct row spacing effects. Only one seeding rate was used for the row spacing comparison, and further work is required to determine the optimum row spacing for sprouting radish.

Seed rate had no significant effect on seed yield, although potential seed yield was reduced at the 15 kg seed rate because per plant performance (pod number and seed yield) was significantly reduced. Seeding rate was examined at only one row spacing, and Kondra (1975) observed that changes in row spacing can affect a crop's response to seeding rate. However it is likely that as with oil-seed rape, final seed yields will not be greatly affected by wide ranges of plant populations (Loof, 1972; Christensen and Drabble, 1984), because population differences can be offset by changes in plant morphology (Scarisbrick and Daniels, 1984).

Sprouting radish has been sown in autumn and spring in New Zealand. For example, of 9 crops surveyed in Canterbury in 1984, 2 had been sown in April, 4 in September, 2 in October and 1 in November (I.C. Harvey, pers. comm.). Sowing date trials have yet to be carried out in New Zealand, but the observation of one grower was that early spring was preferred, as autumn sown crops had a wider variation of flowering date and consequently a greater range of pod maturities (C. Lill, pers. comm.). If a comparison with oil-seed rape is used, spring crops should be sown by mid September so that development can be completed before unfavourable conditions e.g. moisture stress and insect damage, reduce yields (Dawkins, 1983).

Differences between potential and actual seed yields in this trial ranged from 69 to 278 g m^{-2} depending upon treatment, and these losses occurred during threshing and cleaning. In contrast to oil-seed rape where 'pod shatter' is a serious problem (Dawkins, 1983), pods of sprouting radish are indehescent, which makes the removal of seed from the pod difficult. Seed is therefore easily damaged during threshing.

The trial was harvested when seed moisture content was determined to be 9% for each treatment. However, many pods were not split and passed through the header, or were partially split without the seed being removed from the pod. The use of desiccants and methods of harvesting sprouting radish seed requires further work, because seed which fails to meet sprouting quality standards is virtually worthless.

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