Seed quality effects on seedling emergence, plant stand establishment and grain yield in two-row barley

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Seed viability and vigour play important roles in seedling emergence, plant stand establishment and yield potential. The majority of cereal fields in Finland are typically sown with farm saved seed (FSS). If the quality of the seed is not known, there can be insidious yield reduction. This research was conducted to study the effects of seed quality on seedling emergence rate, seedling number and yielding capacity. The study comprised three-year field experiments conducted during 2007–2009, established at three sites: Jokioinen, Nousiainen and Ylistaro. Spring barley cultivars Saana (2007) and Annabell (2008-2009) were sown at rate of 500 germinating seeds m^{-2}. Five seed lots were included as treatments: farm saved seed (FSS); down-graded seed $_{<2.5\,mm}$ ($FSS_{<2.5\,mm}$); upgraded seed $_{>2.7\,mm}$ ($FSS_{>2.7\,mm}$); upgraded seed $_{>2.7\,mm}$ with disinfection ($FSS_{>2.7\,mm\,+\,dis}$); and commercial certified seed with disinfection (CCS). Up- and down-graded seed lots ($FSS_{<2.5\,mm}$, $FSS_{>2.7\,mm}$, and $FSS_{>2.7\,mm\,+\,dis}$) all originated from the FSS. Seedling emergence rate was measured from the time when coleoptiles started to break through the soil surface. The number of seedlings (3 × 1 m row per plot) was recorded at five-day intervals four times from the same rows. Plots were harvested at physiological maturity and grain yield (kg ha^{-1}), hectolitre weight (HLW, kg) single grain weight (SGW, mg) and grain protein content (%) were recorded. Seed lots of CCS and $FSS_{>2.7\,mm\,+\,dis}$ enhanced seedling emergence rate and increased the number of plants compared with other treatments. These two seed lots also produced the highest grain yield and had the lowest grain protein. Seed quality had an apparent effect on plant stand establishment and grain yield. A seed lot effect was evident despite identical targeted sowing rates that took into account germination rate and seed weight. Therefore, differences in seedling emergence and yielding capacity were likely outcomes of variation in seed vigour among the five treatments.

Key-words: barley, emergence, plant stand, seed quality, yield

Introduction

Seed viability and vigour determine how successfully seedlings emerge, plant stand is established and yield potential is built up. Seed viability generally refers to germination rate whereas seed vigour represents the capacity of the seed to develop and produce a normal seedling under various growing conditions. These two traits are affected by several factors, starting from grain-filling period and continuing throughout harvest and storage conditions. Seed age, moisture content, infection by seed-borne pathogens and seed weight are among the characteristics associated with seed viability and vigour (Doling 1968, Ching et al. 1977, Khah et al. 1989, Gan et al. 1992, Chastain et al. 1995, Grilli et al. 1995, Reddy et al. 1999, Nonogaki et al. 2010). Differences between germination rates in the laboratory and seedling emergence rates in the field may vary considerably: seed lots with a germination rate of 85–100% produced seedlings at rates of 47 to 93% according to Steiner et al. (1989). This difference between germination rate and emerged seedling number was attributed to differences in seed vigour under varying conditions (Steiner et al. 1989). Accordingly, seed performance is a consequence of an interaction between seed vigour and prevailing conditions such as sowing depth, soil characteristics, soil moisture and temperature.

The shoot apex initially produces the leaf and tiller primordia and after a transitional phase, the spikelet and floral organs (Bonnett 1961; Waddington et al. 1983). Thus, yield formation actually begins already at seedling emergence. During a short intensive growing season, as prevails in northern Europe, cereal growth and development are rapid due to the long days. This secures successful crop production in just 80 to 110 days (Peltonen-Sainio and Rajala 2007; Peltonen-Sainio et al. 2009a). Accelerated development rate reduces a plant's potential to compensate for potential setbacks occurring during emergence and early plant stand formation (Peltonen-Sainio et al. 2009a). This emphasizes the central role of seed quality and successful sowing to facilitate even and adequately dense seedling emergence. Successful seedling emergence sets the foundation for the formation of full (= adequately dense) plant stands that utilise available water and radiation efficiently from the start of the intensive growing period (Peltonen-Sainio et al. 2003; Peltonen-Sainio et al. 2009a).

Depending on a farmer's preferences, either FSS or CCS are used to sow a crop. Unlike in other European countries, in Finland most cereal fields are typically sown with FSS (Peltonen-Sainio et al. 2003). The proportion of FSS varies among cereal species and years, ranging from 63% to 80% (Fig. 1). The quality control for FSS depends on the farmer running the required tests. For the certified
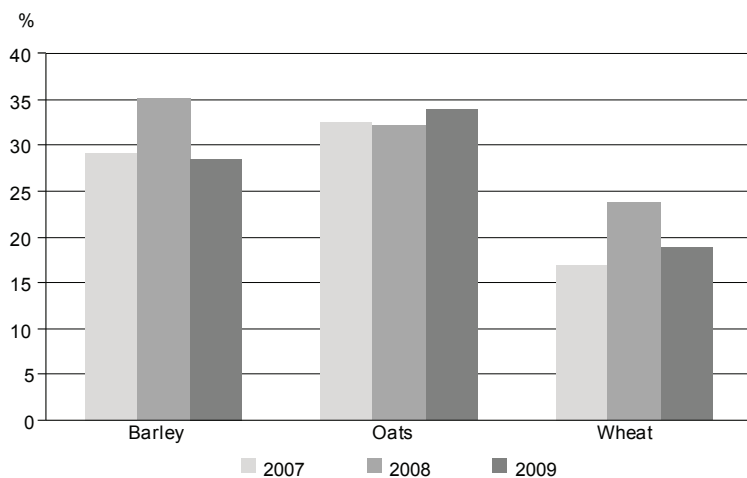

Fig. 1. The certified seed percentage (%) in spring cereal sowings. Source: Nordman (2010).

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seed sector, the seed quality is regulated by employing a threshold value for seed germination and other seed quality requirements, which are set by legislative authorities (http://www.evira.fi). Compared with viability (=germination rate), seed vigour is more laborious to measure and define and it is not included in regular seed testing and approval programmes. However, seed vigour may strongly affect seedling emergence rate, plant stand establishment and yield performance, especially under less favourable growing conditions (Steiner et al. 1989, López-Castaňeda et al. 1996). This research was conducted to study the potential differences in seedling emergence rate, seedling number and yielding capacity of seed lots with similar germination rates but varying in other quality traits. Special interest was to reveal potential differences in yielding capacity and ranking of seed lots when grown in varying growing conditions.

Material and methods

This study comprised three-year field experiments conducted during 2007–2009 established at three sites: Jokioinen (60° 48′ 3 N, 23° 28′ 5 E), Nousiainen (60° 35′ 6 N, 22° 50′ 0 E) and Ylistaro (62° 56′ 3 N, 22° 31′ 0 E). Spring barley cultivars Saana (2007) and Annabell (2008–2009) were sown at 500 germinating seeds m^{-2}. Sowing rate was calculated using following equation

$$kg\ ha^{-1} = \frac{aimed\ density\ (plants\ m^{-2}) \times thousand\ grain\ weight\ (g)}{germination\ rate\ (\%)}$$

Thus all plots were sown with an identical number of viable seeds (500 seeds m^{-2}) and thereby the potential seed lot effect on growth was not a consequence of different germination rates.

Plot size was 6 m^2 in Jokioinen and Nousiainen and 10 m^2 in Ylistaro. Plots were fertilized with NPK- (23-3-6) fertilizer at 80 kg N ha^{-1}. Weeds were controlled using MCPA, clopyralid, fluorox-ypry –compounds (trademark Ariane S). Five seed lots (treatments) were compared: FSS; FSS$_{<2.5\ mm}$; FSS$_{>2.7\ mm}$; FSS$_{>2.7\ mm\ +\ dis}$ (disinfection by using triconazole and imazalil -compounds, trademark Robust); and CCS. FSS$_{<2.5\ mm}$, FSS$_{>2.7\ mm}$, and FSS$_{>2.7\ mm\ +\ dis}$ originated from the same FSS material, which was produced by applying good farm management practices. Seed lot FSS$_{<2.5\ mm}$ consisted of seeds passed through a 2.5 mm sieve plate, whereas for the FSS$_{>2.7\ mm}$, and FSS$_{>2.7\ mm\ +\ dis}$ lots the seeds remaining on the 2.7 mm sieve plate were used. Germination rate and single grain weight of seed lots are shown in Table 1.

Seedling emergence rate was assessed at the Jokioinen site (2008–2009) when coleoptiles began to emerge through the soil surface. At first counting, three rows per plot were marked (length 1 m). Number of seedlings was counted at five-day intervals four times at the same marked seeding rows. At physiological maturity, plots were harvested and grain yield (kg ha^{-1} at 15% moisture content) hectolitre weight (HLW, kg) and single grain weight (SGW, mg) were measured. Grain N concentration was measured with a NIR analyzer (Foss InfraXact).

Trial set-up was a randomised block design with four replicates. All statistical analyses were carried out with PASW Statistics 18.0 software using the MIXED procedure (Littell et al., 1996). In the model, seed lot, trial site and year were considered to be fixed effects, while blocks nested within trial and year were considered to be random when computing means for grain yield and yield quality parameters. By considering seed lot, trial site and year as a fixed effect, the model was more appropriate to reveal potential seed lot by growing condition interaction, i.e. seed lot differences in yielding capacity when grown in varying growing conditions (site and year). Comparisons of treatments were done using the Bonferroni test.

Seed lot was considered to be a fixed effect, while year and block were considered to be random when computing means for seedling numbers of cv Annabell for trials carried out at Jokioinen.

Table 1. Single grain weight (SGW) and germination rate (%) of seed categories. +, disinfectant treatment; - no disinfectant treatment.

Year	Cultivar	Seed lot	Seed lot abbreviation	SGW mg	Germination %	Disinfectant
2007	Saana	farm saved seed (FSS)	FSS	38.8	96	-
2007	Saana	downgraded FFS	$FSS_{<2.5\,mm}$	30.7	96	-
2007	Saana	upgraded FSS	$FSS_{>2.7\,mm}$	48.0	96	-
2007	Saana	upgraded $_{+dis}$infected FFS	$FSS_{>2.7\,mm\,+\,dis}$	48.0	96	+
2007	Saana	commercial certified seed	CCS	51.2	94	+
2008	Annabell	farm saved seed (FSS)	FSS	41.0	89	-
2008	Annabell	downgraded FFS	$FSS_{<2.5\,mm}$	32.7	89	-
2008	Annabell	upgraded FSS	$FSS_{>2.7\,mm}$	45.3	89	-
2008	Annabell	upgraded $_{+dis}$infected FFS	$FSS_{>2.7\,mm\,+\,dis}$	45.3	89	+
2008	Annabell	commercial certified seed	CCS	50.7	92	+
2009	Annabell	farm saved seed (FSS)	FSS	41.7	91	-
2009	Annabell	downgraded FFS	$FSS_{<2.5\,mm}$	37.2	91	-
2009	Annabell	upgraded FSS	$FSS_{>2.7\,mm}$	43.6	91	-
2009	Annabell	upgraded $_{+dis}$infected FFS	$FSS_{>2.7\,mm\,+\,dis}$	43.6	91	+
2009	Annabell	commercial certified seed	CCS	50.7	92	+

CCS = commercial certified seed; FSS = farm saved seed.

Results and discussion

CCS and $FSS_{>2.7\,mm\,+\,dis}$ seed lots enhanced seedling emergence rate and increased the number of plants compared with the other seed lots at trials carried out in Jokioinen (Fig. 2). Improved emergence was evident despite similar numbers of germinating seeds per m². Apparently, seed treatment with fungicide improved seed's potential to produce live and vigour seedlings to emerge through the soil. Similar response has been reported in an extensive Swedish study carried out on several locations and years (Johnsson et al. 1998). Under field conditions, also seed vigour is known to affect seedling emergence (Khah et al. 1989, Steiner et al. 1989, López-Castañeda et al. 1996). Post-sowing drought periods occur regularly in the main cereal production areas of Finland (Pajula and Triipponen 2003, Peltonen-Sainio et al. 2010). Sparse precipitation in conjunction with heavy soils (typically clay in southern Finland) set high requirements to seed vig-

our (Peltonen-Sainio et al. 2009a, Peltonen-Sainio et al. 2010). Hence, actual seedling number may differ markedly from potential seedling emergence based solely on germination rate (Fig. 2). This was evident in this study as the number of emerged seedlings did not reach the target 500 seedlings m^{-2} for any of the seed lots. The range of emerged seedlings was from 68% to 86%, which is comparable with the values presented by Steiner et al. (1989). Barley has the highest tillering capacity of the cereal species grown in northern growing conditions (Peltonen-Sainio et al. 2009b). Despite of this, sparse and/or uneven seedling emergence may result in yield reductions in a short and intensive growing period (Peltonen-Sainio et al. 2009a,b).

Seed lots varied in yielding capacity (Table 2). The grain yield varied within trial sites and between years. However, the ranking of seed lots was similar over the years and sites and no significant interaction between seed lots, trial sites and years was recorded. CCS produced the highest grain yield, followed by seed lot $FSS_{>2.7\,mm\,+\,dis}$. These
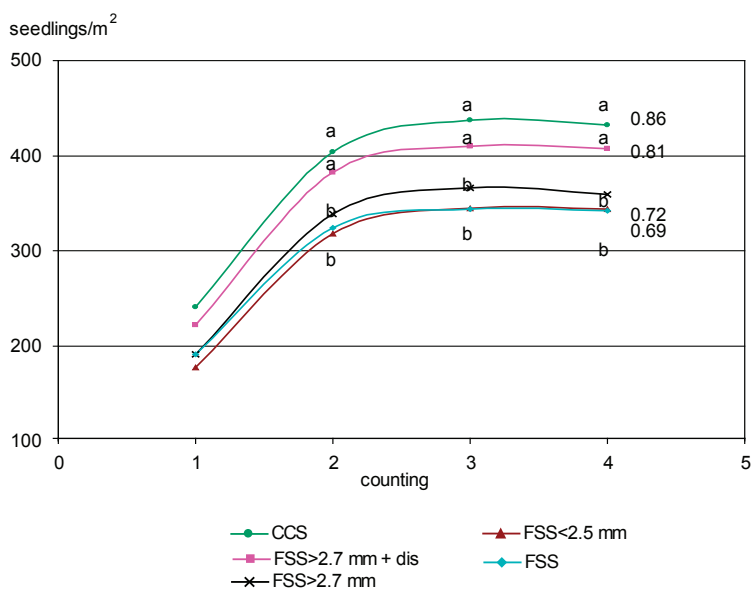
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Fig. 2. Number of seedlings per square meter after different seed categories of cv Annabell. Counted at Jokioinen trial site 2008–2009. Countings were carried out at 5 days intervals. Numbers in the box indicate the ratio of realised and aimed seedling number. The same lowercase letter indicates no statistical difference at $p < 0.05$. CCS = commercial certified seed; FSS = farm saved seed.

Table 2. Seed lot effect on grain yield (kg ha^{-1}), protein concentration (%), hecto liter weight (HLW, kg) and single grain weight (SGW, mg). Protein is shown at 0% moisture content, other results at 15%. Results are shown as means over year, trial site and genotype. The same lowercase letter indicates no statistical difference at $p \leq 0.05$ in the test of Bonferroni.

	Yield kg ha^{-1}		Protein %		HLW kg		SGW mg	
FSS	5692	bc	11.6	a	67.3	a	44.8	a
FSS$_{<2.5\ mm}$	5506	c	11.6	a	67.3	a	44.9	a
FSS$_{>2.7\ mm}$	5820	b	11.6	a	67.2	a	45.2	a
FSS$_{>2.7\ mm + dis}$	6126	a	11.3	b	67.3	a	44.9	a
CCS	6346	a	11.3	b	67.4	a	45.3	a
p-value	< 0.001		< 0.001		0.948		0.612	
sem	80.1		0.06		0.18		0.29	

CCS = commercial certified seed; FSS = farm saved seed; sem = standard error of means.

two seed lots expressed also higher seedling emergence rate when counted at Jokioinen trial site. Improved seedling emergence has likely a positive effect on yield performance (Steiner et al. 1989, López-Castañeda et al. 1996). Seed restoration actions (up-grading and seed disinfection) of FSS improved yield performance. When comparing seed lots FSS$_{>2.7\ mm}$ and FSS$_{>2.7\ mm + dis}$, seed disinfection increased grain yield by 300 kg ha^{-1}. This

yield improvement is comparable with the results presented previously in other Nordic studies (Tahvonen et al. 1995, Johnsson et al. 1998). CCS and FSS$_{>2.7\ mm + dis}$ attained a slightly lower grain protein concentration (%) as compared with other seed lots (Table 2). In contrast with the general protein requirements for feed and food, low protein content is required in malting barley (Peltonen-Sainio et al. 2003). Yield and grain protein

are typically negatively correlated (Boonchoo et al. 1998), which was the case also in this study. Hence, any increase in grain yield using the same available growth resources (namely nitrogen) will likely result in reduction in grain protein concentration. Even moderate reduction in grain protein may determine whether yield ends up for feed or malting. This translates into a substantial difference in the value of the yield as malting barley attracts a higher price than feed barley. Despite of lower grain protein concentration in CCS and $FSS_{>2.7\,mm\,+\,dis}$ seed lots, these two produced the highest protein yield (kg protein per hectare). This means more efficient use of nitrogen to build up grain yield. Other quality traits, like single grain weight (mg) and hectolitre weight (kg), were not affected by seed lot (Table 2).

The seed weight effect was also emphasised in this experiment as both up- and down-grading of yielding capacity. $FSS_{<2.5\,mm}$ was associated with a grain yield reduction of ca. 200 kg ha^{-1} when compared with FSS, ca. 300 kg ha^{-1} when compared with $FSS_{>2.7\,mm}$ and of ca. 600 kg ha^{-1} when compared with $FSS_{>2.7\,mm\,+\,dis}$ (Table 2). The seed weight effect on yielding potential is ambiguous, but some literature reports a positive correlation between them (Mikkelsen 1963, Hampton 1981, Chastain et al. 1995). Accordingly, grading of the seed lot seems to improve yield formation. FSS is often heterogeneous regarding seed weight (Peltonen-Sainio et al. 2011) and therefore grading is an important procedure for improving and stabilising the seed quality of FSS.

FSS is used extensively by Finnish farmers (Fig. 1). A common reason for this is the low price paid for grain and farmers are apt to reduce production costs by using FSS. However, according to our results, CCS produced the highest grain yield. Also, good quality FSS, when it is graded and treated with disinfectant, can be comparable to the quality of CCS, but these restoration actions also increase the costs of FSS. To justify the use of more expensive seed (CCS or $FSS_{>2.7\,mm\,+\,dis}$) merely for economic reasons, the yield improve-ment needs to exceed the seed cost difference with unrestored FSS. The relatively strong fluctuations in cereal market price during recent years somewhat complicate the economic comparison between seed lots, and consequently a farmer's decision making. In our estimations approximately 150 to 250 kg ha^{-1} more grain is needed to cover the difference in cost between CCS and $FSS_{>2.7\,mm\,+\,dis}$, while 300 to 500 kg ha^{-1} covers the difference between CCS and unrestored FSS, and 100 to 200 kg ha^{-1} covers the difference between $FSS_{>2.7\,mm\,+\,dis}$ and FSS. These rough threshold values were met in this study (Table 2). The economic assessment of the situation changes even more towards a high quality seed advantage when other issues are taken into account. If other inputs (cultivation, fertilisation, plant protection) are used at a similar level, then the low quality seed with lower yielding potential inevitably reduces the input use-efficiency. This represents a drawback in economic as well as environmental terms.

Conclusions

In this study, seed quality had an apparent effect on plant stand establishment and yield. Differences were obtained despite similar germination rates for the various seed lots and identical seed rates of germinable seeds (500 germinating seeds m^{-2}). Thus, differences in seedling emergence and yield performance were the outcome of variation in seed quality. Higher yield improves input use-efficiency, which is an important aspect of economical results and environmental impact of cereal production.

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