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Review article

Characterising strengths, weaknesses, opportunities and threats in producing naked oat as a novel crop for northern growing conditions

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Naked oat (*Avena sativa* ssp. *nuda* L.) is the highest quality small-grain cereal that can be grown at the northernmost margin of cereal production. It remains an under-utilised crop and it contributes less than 0.1% to the total oat area in Finland. In general, limited interest in growing naked oat more extensively is attributed to its weaknesses, which ironically result from nakedness that improves the quality of the crop. This paper reviews the available literature and assesses the balance of the arguments for and against naked oats. Results from the study were transformed into quantitative variables and analysed for strengths, weaknesses, opportunities and threats (SWOT) using an analytical hierarchical process. As the importance of different SWOT-factors depends largely on targeted end-use of yield, separate analyses were done for use of naked oats as on-farm feed and as an input for the feed and food industry. If we aim at increasing area under naked oat in Finland, the most feasible starting point would be on-farm feed. In this case, strengths (high nutritional quality and energy content) out-weighed weaknesses (sensitivity to grain damage) and threats (problems in germination). Increasing naked oat production in this respect is likely to encourage solving the remaining problems that deter industry. Threats (availability) regarding the feed industry and weaknesses (incomplete expression of nakedness) in the food industry out-weighed strengths (high nutritional quality and storability) and opportunities (potential niches).

Key words: breeding, cultivation, feeds, food, grain, harvesting, oats, quality, storage, yields

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Introducing reasons for evaluating potential of naked oat

Oat (*Avena sativa* L.) grain is excellent in nutritional quality and has high metabolisable energy content compared with other small-grain cereals, but only when the palea and lemma, termed hulls, which surround the caryopsis are excluded (Peltonen-Sainio et al. 2004a, b). Hull content is a major reason for lack of interest in growing and using oat in many countries where barley (*Hordeum* vulgare L.) and wheat (*Triticum aestivum* L.) predominate (Burrows 1986). Hence, considerable plant breeding effort has been directed at reducing hull content and increasing groat content in conventional oat (Souza and Sorrells 1988, Forsberg and Reeves 1992). Despite significant progress having been made in lowering hull content (Rekunen 1988), the presence of hulls limits the attractiveness of oat as feed and food. This has, together with mechanisation of agriculture and decrease in number of workhorses, resulted in a drastic reduction in oat production compared with barley and wheat (Fig. 1a). National Farm Policies may also have discouraged oat producers in many regions. There has been no marked and permanent upturn in area under oat, although it appears to have stabilised. In light of this, the capacity of naked oat *(A. sativa* ssp. *nuda)* to dehull when fully matured represents an important advantage over conventional oat that is characterised by lignin-rich, straw-like hulls (Valentine 1987, 1990) contrary to thin, papery and far less-lignified hulls of naked oat (Ougham et al. 1996).

Naked oat is not a novel crop in the strictest sense. It has a relatively long history in agriculture, probably going back to 500 AD. It was domesticated in China and it is still today a common crop in certain regions of that country (Hsun and Maurice 1992). From China it spread to Europe as a weed and was subsequently domesticated in England, in Norfolk and Suffolk, in the 17th century according to the earliest reliable archaeological excavations (Gerard 1597, ref. Valentine 1995).

Cultivation of naked oat has grown during the last decade and now occupies 4500–6000 hectares in UK with considerable increase in average yield (Fig. 1b). There are also prospects for short-term, marked expansion in area under naked oat in UK (Christopher Green, personal communication, 6 May 2003). There are no firm indications that naked oat has been cultivated in the past in Finland, at least not to a significant extent (Hannu Ahokas, personal communication, 20 March 2003). At the end of the 20th century, the area under naked oat in Finland was only 400 hectares and in 2002 285 hectares (Anneli Partala, personal communication, 30 April 2003). This contributes 0.1% to the total oat acreage, but indicates the potential for more comprehensive production of naked oat as oat is an established cereal crop.

Weighing strengths and weaknesses on the basis of available information

Experience in cultivation

Oat is grown extensively in Finland and Sweden in comparison with other important oat producing countries (Fig. 1a). For example, in 2002 nearly 40% of the cereal area (barley, oat and wheat) in Finland was under oat. The figure was nearly 30% for Sweden but less than 10% for other countries including Canada, UK and USA. Experience in oat cultivation has accumulated over generations, creating in principle, an excellent starting point for introducing naked oat to farmers. The readiness to take naked oat into large-scale cultivation in Finland is a strength, especially as it does not require any additional investment in farms.

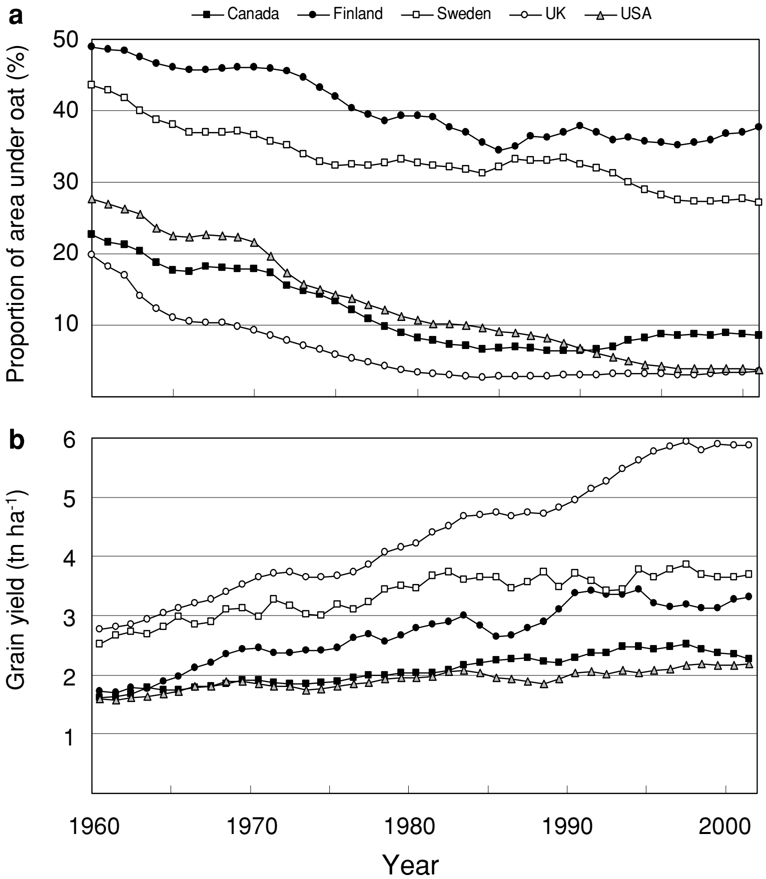

Fig. 1. Trends in a) area under oat relative to that for other small-grain cereals (barley, oat and wheat) and b) grain yield in Canada, Finland, Sweden, United Kingdom and USA since 1960s. Each point represents a five year running mean (source: http://www.fao.org).

Adaptation to northern growing conditions

Finland represents the northernmost margin for large-scale cereal production. In general, oat grows and yields well under these relatively cool conditions as there is adequate precipitation without long drought periods (Mukula and Rantanen 1989). Oat is often cultivated on lands not deemed suitable for barley and wheat (Peltonen-Sainio 1999). This is particularly true with acid soils typical of Finland (Mäkelä-Kurtto and Sippola 2002), as oat is the only spring cereal well adapted to low soil pH. Long days in conjunction with relatively high temperatures soon after sowing during early growth stages in early May hasten the development of oat. The double ridge stage is reached once two leaves have emerged, and development of the panicle starts through initiation of the first spikelet primordia (Peltonen-Sainio and Pekkala 1993, Peltonen-Sainio 1994, 1999). This is also true for naked oat (Peltonen-Sainio, unpublished data). Maturation of an oat stand requires accumulation of temperature to about 1000°C degree days, depending on earliness of the cultivar (5°C as base temperature, Mukula and Rantanen 1987). When earliness of naked oat cultivars is similar to that of conventional cultivars released in Finland, there are no expected risks related to grain maturation. However, sensitivity of naked oat grains to mechanical damage induced by high grain mois-

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ture (Kirkkari et al. 2001, Peltonen-Sainio et al. 2001a) is reduced by earliness. An alternative to reducing such risks is to grow naked oat, like wheat, only in the most southern regions of Finland that are characterised by the longest growing season (Mukula and Rantanen 1987). Contrary to the recent trend of winter oat replacing spring oat in the UK (Semundo Ltd 1995), only spring oat is likely to have a future in Finland. Winter oat does not have the ability to survive under low temperatures and when covered by snow for long periods – 110 to 130 days in the southwest and western coastal regions and 160 days in central Finland (Mukula and Rantanen 1987). Thus, it can be concluded that spring-type naked oat is well adapted to grow and yield under northern growing conditions, which can be regarded as a strength.

Crop management

If long tradition in cultivation of conventional oat can be regarded as a strength regarding readiness for cultivation, it may also be a burden if the special features of naked oat are not taken into account in cultivation. This is especially noteworthy as oat is regarded among farmers as a crop that grows well without ‘substantial inputs and care’. Production of high quantity and quality yields of naked oat requires some fine-tuning of crop management. For example, Peltonen-Sainio (1994) suggested that a seeding rate about 10% more than for conventional oat is needed for naked oat (some 550 viable seeds per square metre) because seedling emergence, and hence number of panicles per square metre, was found to be less for naked than for conventional oat. Rapid establishment in association with early and full ground coverage is targeted also in naked oat. Under northern growing conditions 46% of variation in grain yield, 71% for panicle weight, 76% for number of grains per panicle, and 71% for panicle filling rate in oat, including the naked type, was attributed to pre-anthesis leaf area duration (LAD), a trait that takes into account both green area and its persistence (Peltonen-Sainio 1997b, Peltonen-Sainio et al. 1997). Reduced seedling emergence in naked oat, however, was not attributed to lower germination as the number of seeds needed per square meter was determined on the basis of grain weight and germination. Hence, it was concluded that naked oat grain was less vigorous and, to avoid formation of sparse plant stands, a 10% increase in seeding rate is needed to compensate for the reduced vigour (Peltonen-Sainio 1994). This was later supported by the finding that naked oat seedlings were less able to grow through 5 cm than through 2 cm of sand in laboratory tests (Peltonen-Sainio et al. 2001a). Recorded reduction in grain vigour is, however, likely to result from smaller grains with fewer carbohydrate reserves only in the case when more than two grains are produced per spikelet, as tertiary grains are known to be particularly small (Palagyi 1983). Therefore, mechanical damage to the grain is likely to be the principal contributor to reduced grain vigour. When attempting to improve seedling establishment through use of fungicidal seed coating, special care has to be taken to not cause any further reduction in seed vigour. Due to the uncertainties related to seedling emergence and crop establishment, reduced grain vigour and the need for higher seeding rates are weaknesses.

Except for using 10% higher seeding rates for naked oat, crop management largely resembles that for conventional oat (Peltonen-Sainio 1997a, Peltonen-Sainio and Rajala 2001). However, when fully matured, careful harvesting using low combine harvester cylinder speed is needed to ensure high germination rate (Valentine and Hale 1990, Kirkkari et al. 2001). Narrowing the concave clearance did not affect germination (Kirkkari et al. 2001). By these means high quality of naked grains in the field is maintained. The special features of crop management for naked oat are not barriers to its cultivation in Finland and hence, the parallel between naked oat and other spring cereals with respect to crop management, requiring no additional investment other than higher seeding rate, is regarded as a strength.

Yielding ability

An appropriate comparison of yielding ability of naked oat and conventional oat requires that the stands of naked oat be established without a major difference in seedling number compared with conventional oat, i.e., 10% higher seeding rate is used to compensate for lower grain vigour (Peltonen-Sainio 1997a). It is also important that the comparison is based on groat yields or grain number per unit land area, as 20–25% of conventional oat grain is low quality, straw-like hulls. This is also the case for incompletely dehulled naked oat grain, but to much lesser extent (Ougham et al. 1996). Under northern growing conditions, groat yield of naked oat is already similar to that of conventional oat: depending on cultivars compared, it may be up to 10% higher, equal to or as much as 20% lower (Peltonen-Sainio 1994, 1997a, Kangas et al. 2001).

Multiflorous spikelets of naked oat (Fig. 2) are still considered to be responsible for lower yielding ability in comparison with conventional oat. Some naked oat lines are able to produce up to 10–12 florets per spikelet (Burrows 1986). Breeding efforts have, however, resulted in greater abortion rate of higher ranking florets at the top of the spikelet (Burrows 1986). Often in the UK two to four grains are set per spikelet (Valentine 1995). In Finland, naked lines tended to produce fewer spikelets per panicle but more grains per spikelet than conventional oat (Peltonen-Sainio 1994), though naked lines differed in this respect, indicating potential for breeding. However, naked lines tended to have only limited ability to produce more than two to three grains per spikelet in experiments conducted in Finland (Peltonen-Sainio 1994, 1997a). This may indicate that due to rapid development and growth (Peltonen-Sainio and Pekkala 1993), only part of the potential in floret and grain set per spikelet is expressed. This is supported by the finding of Jenkins (1973), who showed that the proportion of multiflorous spikelets was greatest when grown with less than a 15 hour daylength. Reduced tertiary grain set favours yield formation: when comparing harvest indices of naked and conventional oat on the basis of groat yield. They did not differ from each other, indicating similarities in partitioning of assimilates for yield (Peltonen-Sainio 1994). Ability of naked oat cultivars to produce groat yields similar to those of conventional oat, is a strength, particularly considering that for a long time conventional cultivars easily out-yielded the first generations of naked oat (Valentine 1995). Plant breeding has already managed to provide improved, high yielding cultivars (Kangas et al. 2001).

Nutritional quality

Naked oat is superior in quality compared with conventional oat as it is characterised by high digestible energy content with both having a favourable combination of amino acids and min-

Fig. 2. Naked oat panicle with multiflorous spikelets (Photo: Magnus Scharmanoff/MTT files).

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erals (Doyle and Valentine 1988, Valentine 1995). The quality of naked oat is very similar to that of dehulled conventional oat (Peltonen-Sainio et al. 2004a). Hence, the absence of the encapsulating palea and lemma are the major determinants of high metabolisable energy content of naked oat groat. Naked oat offers a promising alternative for nutrient dense, low fibre diets. The only exception with respect to the corresponding quality in dehulled oat *versus* naked oat groat quality is that naked oat grain is likely to have less β-glucan (Givens et al. 2000). Numerous studies have indicated, not surprisingly, that the high nutritional value and metabolisable energy content of naked oat has produced encouraging results in feeding experiments with horses, pigs, poultry and cattle (Cave and Burrows 1985, Maurice et al. 1985, Myer et al. 1985, Hsun et al. 1986, Givens and Brunnen 1987, Cave et al. 1990, MacLean et al. 1994, Poste et al. 1996) similar to that of partially dehulled oat (Pettersson et al. 1987, 1997).

Grain quality is not, however, currently determined solely on the basis of grain composition, nutritional quality and metabolisable energy content, but also in terms of whether the grain mass is free from anti-nutritional factors, contaminants and pesticide residues. In the case of naked oat, special attention has been paid to its expected sensitivity to pathogens, particularly *Fusarium* induced infections (Fig. 3). Bruised and broken areas of the grain surface of the unprotected naked groat encourage pathogen invasion (Picman et al. 1984). In the studies of Peltonen-Sainio et al. (2001a, 2001b), some *Fusarium*-synthesised mycotoxins, such as deoxynivalenol, nivalenol, HT-2 toxin and T-2 toxin, were found in naked and conventional oat. Furthermore, no trend was established for grains threshed at high grain moisture exhibiting higher concentrations of mycotoxins. On the basis of a two-year survey, mycotoxins neither favoured naked oat nor were associated with degree of grain damage (Peltonen-Sainio et al. 2001a). Grains are typically artificially dried after harvest, prior to storing and are kept dry at naturally low temperatures, which makes risks related to storage pathogen infection negligible. Sinha et al. (1979) indicated that naked oat quality was lowered by storage fungi, such as *Aspergillus versicolor*, and pests, only when grain moisture during storage increased. We conclude that high quality of naked oat grains and applicability of naked yield for multiple feed purposes are evident strengths.

Grain damage

Grain crops in Finland are often threshed when the moisture content of the grain is approximately 21–23% (Aaltonen et al. 1999). Threshing and drying exposes grains to mechanical stress and they are damaged, particularly when threshed while moist (Valentine and Hale 1990, Kirkkari et al. 2001, Peltonen-Sainio et al. 2001a). This is particularly true for naked oat, as the groat and embryo are unprotected when freed from the lemma and palea (Valentine and Hale 1990, Pel-

Fig. 3. Germinating seed of naked oat suffering from fungus infection (Photo: Magnus Scharmanoff/MTT files).

tonen-Sainio et al. 2001a). Mechanical injuries typically include bruises, contusions and scratches. Naked oat grain is especially vulnerable as it is softer than wheat and barley. Peltonen-Sainio et al. (2001a) indicated that ten percent increase in grain moisture content at harvest resulted in about 11 percent decrease in proportion of normal seedlings in a blotting paper test, although no additional grain breakage and loss of germination occurred during drying and transfer of naked grain mass (Peltonen-Sainio et al. 2001b). This reduction was principally due to threshing-induced lethal injuries to the embryo. Cultivar differences in sensitivity to grain damage were evident (Peltonen-Sainio et al. 2001a), and the major determinants were groat hardness and grain size. The harder groat was more sensitive to breakage while a higher proportion of smaller grains tended to increase resistance to groat breakage and loss of germination ability at increasing levels of grain moisture at harvest (Peltonen-Sainio et al. 2001a). In addition, results from laboratory tests showed that increased grain moisture at harvest and concomitant damage in grains were associated with faster seedling elongation. This may be due to faster imbibition of grains with surface damage. Sensitivity of naked oat grain to damage is, however, evidently the major indisputable weakness.

Expression of nakedness

Some grains of naked oat retain their hulls after threshing (Lawes 1971, Lawes and Boland 1974, Ougham et al. 1996). The extent of nakedness depends on cultivar and growing conditions. For example, Kangas et al. (2001) conducted experiments in three locations in Finland and found cultivar differences in hull retention, ranging from 0.7% to 13% with variation also caused by year and location. When growing conditions favour maturation, grain is better able to thresh free from hulls during harvest. Lawes and Boland (1974) showed that high temperatures favoured, while cool temperatures reduced, removal of hulls. The importance of reaching full maturity to realise complete expression of nakedness was also supported by the finding that under Norwegian growing conditions, test weight of conventional oat correlated strongly with dehulling percentage (Gullord 1986). An additional study showed that screening naked groats after threshing resulted in different size distribution compared to that recorded after dehulling grains by hand and then sorting (Kirkkari et al. 2004). From this study, it was concluded that smaller grains in particular retained more hulls, which may indicate that late developing tertiary grains as well as those in the lowest part of the panicle are especially prone to hull retention. This also provides further support to the idea that full maturity is associated with better ability to dehull during harvest.

Neither the characteristic incomplete dehulling capacity nor the annual variation in hull content of naked oat due to differences in maturity level of the grains at harvest are attractive features. The degree to which incomplete dehulling is a weakness greatly depends on whether the yield is used for on-farm feed, where it does not represent a problem (Peltonen-Sainio et al. 2001b), or whether for the food industry, where even small proportions of hulls have to be removed before groats are ready for further processing. Hence, the food industry is generally unable to benefit from using naked oat instead of conventional oat (Forsberg and Reeves 1992).

Storability

In general, artificially drying grain immediately after harvest is a standard procedure in Finland because only rarely does harvest take place when grain moisture is less than 14%. Grain quality is consequently high and there are few storage mould problems. Two major issues related to storability of naked oat remain however: tendency for grain to become rancid and contribution of groat hairs (trichomes) to reduced storage quality. Oat contains oils to a much greater extent than most other cereal grains. When grain

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is damaged, lipase enzymes that are mainly localised in the aleurone layer and embryonic tissues are activated (Ekstrand et al. 1992). Enzymatic reactions result in formation of free fatty acids and the oxidation products of unsaturated fatty acid moieties of oat lipid (Bodin 1995, Molteberg et al. 1995). This occurs rapidly e.g. when oat grains are milled or flaked in the food industry and is suppressed through heat treatment that slows the hydrolysis of neutral fats by inhibiting the lipase enzyme (Ekstrand et al. 1992, Bodin 1995). As naked oat grain is very sensitive to damage e.g. during harvesting, it is also more likely to turn rancid in storage.

Welch (1977) studied the tendency of conventional and naked oat to become rancid and found that the longer the grains were subjected to high grain moisture, the higher the proportion of free fatty acids. However, naked oat did not differ from conventional oat in oxidation of fatty acids, except when naked grains were severely bruised (Welch 1977). The evolution of volatile compounds such as pentanal and hexanal, was greatest when grain moisture content was low (10%), and lowest at about 20% moisture content, although it tended to increase when exceptionally high moisture content was reached (Kirkkari et al. 2004). Furthermore, conventional oat tended to produce higher amounts of hexanal than naked oat if differences occurred (Kirkkari et al. 2004). An additional study by Peltonen-Sainio et al. (2004b) with dehulled, conventional oat indicated that production of volatile compounds was not positively correlated with degree of grain damage. Even storage at high temperatures of up to 30˚C did not enhance rancidification processes in terms of production of volatile compounds when grains were stored under dry conditions. However, free fatty acid concentration was increased with increasing rates of groat damage induced with an impact dehuller, but not to an extent that would result in rancid flavour or odour. Marked increase in concentration of free fatty acids was also found by Sinha et al. (1979) as grain moisture content increased above 15%. There are reports (Welch 1977, Sinha et al. 1979, Peltonen-Sainio et al. 2001b) that indicate that naked oat is not sensitive to rancidity caused by grain damage. There are no reports of problems with storability.

Regarding contribution of groat hairs to storability, Forsberg and Reeves (1992) concluded trichomes to be a problem only for their tendency to trap dust and other foreign matter, which attracts storage insects and pathogens. As cereals produced in Finland are always dried to critical moisture content, trichomes are not expected to represent a problem. The potential negative effects of trichomes are their tendency to cause irritation during grain handling. Storability of naked oat is thus comparable with that of conventional oat and can be regarded as a strength.

Potential opportunities and threats in naked oat production

Substitute for exported energy in feed

Doyle and Valentine (1988) emphasised the potential of naked oat to substitute for imported energy, principally, soybean meal and maize gluten used in feed. These crops have high temperature demands for normal growth and thus are not adapted to northern Europe. It was indicated that substituting barley with naked oat would reduce dependence on imported protein feeds (Doyle and Valentine 1988). Since the evaluation of Doyle and Valentine (1988), domestic crop protein production has been discussed widely in Finland. Firstly, the bovine spongiform encepalopathy epidemics (BSE) and crisis drew attention to the need for crop-based protein and energy. Use of meat and bone meal as animal feed is now prohibited and thus there is currently a more urgent need for higher energy crops than in the late 1980s. Furthermore, use of genetically modified (GM) cultivars has become standard in many regions of the world and it is probably only a matter of time before they will gain popularity in Europe. Because GM- and GM-free products have to be kept separate, exporting, storing and handling e.g. GM-free soybean seeds will generate additional costs. Thus there is increased interest in domestic energy-crop production. Another issue is whether naked oat, usually having much less than 20% groat protein when grown in Finland (Kangas et al. 2001), is regarded as an energy crop by the feed industry. It is, however, evident that use of naked oat in feed mixes increases per unit energy content.

In Finland, the feed industry dehulls oat grains prior to use in feed mixes and has invested in oat dehullers. Therefore, only marginal savings will be made through using naked oat instead of conventional oat. Another important issue is whether naked oat will be produced in large enough quantities to attract the feed industry, resulting in higher prices for farmers. It is notable that two-thirds of total oat production in Finland is used as on-farm feed, representing an attractive proposition for expanding naked oat production. When used as on-farm feed, naked oat presents a very interesting opportunity, as dehulling conventional oat requires that farmers invest in oat dehullers or use dehulling services (Peltonen-Sainio et al. 2004a). In light of all these considerations, naked oat can be regarded as an opportunity, although not the sole, and necessarily the most promising, solution when searching for potential crops to increase the level of self-sufficiency in energy and protein production in Finland.

Availability

Naked oat cultivars adapted to northern growing conditions have not been bred as actively as conventional oat and other small-grain cereals. Only one such cultivar has been released in Finland. 'Lisbeth', released in 1994, is early maturing, but very low yielding (Kangas et al. 2001). It has very small grains, associated with improved opportunities to produce seed material with high germination (Peltonen-Sainio et al. 2001a). 'Lisbeth' has not been accepted by farmers, due mainly to its modest yielding ability. Finnish plant breeders have not therefore been encouraged to invest substantially in naked oat improvement. In contrast, in the UK considerably more effort has been devoted to breeding new-generation naked oats. If they mature early enough under Finnish growing conditions, they can be further adapted. However, most are winter cultivars and they cannot be introduced into Finland. This fact and that naked oat users, other than farmers using naked oat as on-farm feed, cannot guarantee continuity of yield supply for industrial processes, are the two major issues associated with availability. This situation is considered a threat to increased naked oat production in Finland in the future.

Targeted user groups and processes

There exist some potential niches for naked oat. Conventional oat is not well suited to monogastric livestock, including poultry and pigs, due to low digestibility and low metabolisable energy content of hulls. Encouraging results have been recorded for naked oat used in feed mixes (Cave and Burrows 1985, Maurice et al. 1985, Myer et al. 1985, Hsun et al. 1986, Givens and Brunnen 1987, Cave et al. 1990, MacLean et al. 1994, Poste et al. 1996). Naked oat, however, has a particular niche as a constituent in diets for racehorses and pets, commanding a high price (Valentine 1995). Furthermore, as discussed earlier, naked oat increases energy content of on-farm feeds, which are often of low nutritional density.

In addition to feed applications, naked oat can be used in processes like malting (Peterson 1998, Wilhelmson et al. 2001), where it provides a special flavour to further processed oat malt based products (Heiniö et al. 2002) such as speciality breads, biscuits, confectionery, and breakfast cereals (Valentine 1995). The major issue in considering malting of conventional oat is whether it is possible with loss of germination when dehulled conventional oat is used or, if not de-

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hulled, how the hulls are separated after malting. These three examples indicate that naked oat is likely to have some extra potential for specific applications, which represents an opportunity. Gaining added value is important as oat is still exported mostly as grain.

Further breeding success

Far fewer resources are invested in breeding naked oat than conventional oat. Possible reasons for this are paucity of clear, economically viable markets and a wish by some breeders not to dilute already limited oat breeding efforts (Valentine 1995). On the basis of earlier discussion, special breeding targets for naked oat in Finland are earliness, high yielding ability achievable e.g. through breeding for fewer multiflorous spikelets (Peltonen-Sainio 1994), and resistance to groat breakage. The last is the most challenging even though some potential traits contributing to reduced grain damage have been introduced (Peltonen-Sainio et al. 2001a). Improvements in yielding ability through increasing number of spikelets per panicle at the expense of number of grains per spikelet is not only likely to result in higher grain yield but also in smaller losses when cleaning and grading the grain mass (Burrows 1986, Peltonen-Sainio 1994). Production of naked oat in Finland cannot, however, be based solely on cultivars produced in more southern areas such as the UK, as earliness is particularly important in naked oat to avoid grain damage. Hence, whether prospects for cultivar development should be regarded as opportunities or threats depends on the balance between potential and actual progress to date. Cultivar development represents an opportunity for producing domestic, new-generation naked oat cultivars that out-yield 'Lisbeth'. The only obstacle is uncertainty over whether the area of naked oat will enlarge as a result of breeding efforts in the future.

Production intensity

If the production intensity of naked oat remains close to what it is today in Finland, no marked increase in research and development in this field is expected. In the late 1990s The National Oat Program of The Ministry of Agriculture and Forestry in Finland conducted three Research & Development projects on naked oat, but no large-scale applications or growth in interest of cultivating naked oat has yet resulted. This is despite encouraging results (Kangas et al. 2001, Kirkkari et al. 2001, Oksman-Caldentey et al. 2001, Peltonen-Sainio et al. 2001a, b). Lack of interest in increasing production beyond current levels clearly represents a threat to the future of naked oat in Finland.

Seed production

When ≥ 85% germination is the target for commercial seed material, grain moisture at harvest should not exceed 15% (Peltonen-Sainio et al. 2001a), which is far less than is usual in Finland (Aaltonen et al. 1999). Even though differences in germination ability occur among cultivars in response to grain moisture at harvest, these are marginal at 85% germination (Peltonen-Sainio et al. 2001a). However, if germination requirement is reduced to 75%, as in the UK, grain moisture at harvest should not exceed 19% to 26% depending on cultivar (Peltonen-Sainio et al. 2001a). In light of these examples, there are only limited possibilities to overcome the problems of being able to produce seed material that fulfils the germination requirement. Hence, only by lowering the germination requirement will the seed production markets be consistent and reliable. There are opportunities through legislation as in the UK. However, the threat exists that growing conditions strongly limit possibilities for producing highly viable grain. Finland would have to request permission from the EU to reduce the germination requirement for naked oat. There has been a possibility for Finnish seed testing authorities to ask for a licence for permanent, instead of annual, reduction in germination requirements for certified naked oat seed, but which has not yet been used. Hence, the current situation represents a threat more than an opportunity for establishing stable seed markets.

Economy

Although hulls protect the groat from damage in conventional oat they represent economic losses in several ways. When drying conventional oat, more energy is needed to remove the additional water from grains because hulls act as barriers to water movement. Also, greater low bulk-density initiated problems are faced in conventional oat compared with naked (Burrows 1986). Due to low weight, the effect of hulls is greater in volume than in weight. Hence, grains are more loosely packed, occupying more room when dried, stored, transported and handled (Burrows 1986). Dehulling conventional oat in industry prior to further processing requires energy that is only partly compensated for by burning the hulls (Peltonen-Sainio 1994). Furthermore, dehulling conventional oat at the farm scale to increase energy content (Peltonen-Sainio et al. 2004a) also represents an expense in investment and energy requirement. The only additional expense when naked oat is used rather than conventional oat is due to the 10% higher seeding rate, which was discussed earlier. In light of these considerations (unpublished data), naked oat is likely to generate savings compared with conventional oat, which can be regarded as an opportunity.

Weighing SWOT factors and groups for different end-use purposes

Evaluation of strengths (S), weaknesses (W), opportunities (O) and threats (T) through SWOT-analysis is commonly used as a planning tool (Kurttila et al. 2000, Pesonen et al. 2000), though it has a major weakness in being subjective and very user-dependent. Knowing this, we based the SWOT-analyses on an extensive literature survey described earlier in this paper, major conclusions from which are compiled in Table 1. We attempted to reduce subjectivity by indicating all the elements that we used in decision-making, i.e., when weighing whether each relevant factor was considered to be a strength, weakness, opportunity or threat.

The first step in SWOT-analysis, after identifying the relevant factors, was to make pairwise comparisons between SWOT-factors within every SWOT-group (Kurttila et al. 2000). The number of factors within each group differed from six in strengths, to four in opportunities and three in weaknesses and threats (Table 1). When within-group comparisons were conducted, each of the two factor combinations was assessed separately and the one having greater strength (weakness, opportunity or threat depending on group analysed) was assigned the higher value. All the given values ranged from one to nine (Kurttila et al. 2000). The greater the difference between factors regarded as strengths, the greater the difference between their priority values. Hence, the given priorities reflected perception of the authors' of this paper about the relative importance of the factors (Kurttila et al. 2000). The SWOT-analysis was done separately for three different scenarios: naked oat used as on-farm feed, produced for the feed industry or for processing in the food industry.

All two factor combinations were gauged separately and therefore comparisons have some inconsistencies. Due to these inconsistencies, priorities must be calculated using eigenfactors for the pairwise comparisons matrix as Kurttila et al. (2000) proposed. Saaty (1977) showed that consistency index (CI) is λ_{max}–n / (n–1), where λ_{max} is the highest eigenvalue and n is the number of factors in the pairwise comparisons matrix. Furthermore, consistency ratio (C ratio) is the ratio of CI and the average consistency index of randomly generated pairwise comparisons ma-

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Table 1. Classification of factors related to naked oat production in Finland as strengths, weaknesses, opportunities and threats with major criteria used in grouping. See justification and related references for criteria in each section in the text.

SWOT groups	Factors within each group	Major criteria for grouping
Strengths	Experience in cultivation	Long tradition in growing conventional oat in Finland.
	Adaptation to northern conditions	Comparable to that of conventional oat. Growing conditions in Finland favour growth of oat. Early maturity needed to sustain high seed vigour.
	Crop management	Comparable to those in conventional oat (except seeding rate; see below). Cultivation requires no additional investments.
	Yielding ability	Comparable to that of conventional oat (in the second-generation cultivars).
	Nutritional quality	Exceptionally high quality cereal grain. Sensitivity to *Fusarium* invasion and mycotoxin production comparable to that of conventional oat.
	Storability	Comparable to that of conventional oat. No indicated groat damage induced hydrolysis of fatty acids.
Weaknesses	High seeding rate	Need for compensating the reduced seed vigour by using seeding rate of 10% higher than for conventional oat. Compensation easy to carry out, but causes additional expenses.
	Grain damage	Sensitivity to grain damage caused by mechanical stress. Causes most of the uncertainty related to production and use of naked oat.
	Expression of nakedness	Nakedness is not fully expressed. Using grain yield for on farm feed face no problems, but due to incomplete expression of nakedness food industry lacks the prominent benefit of using naked oat.
Opportunities	Substitute for imported energy	Naked oat is a potential, under-utilised candidate, though not the only one to substitute for imported energy feed. Need emphasised due to the bovine spongiform encepalopathy (BSE) crisis and domination of genetically modified (GM) soybean.
	Targeted use (niches)	Nakedness offers extra potential for specific, high value applications (racehorse and pet feed, malting).
	Future breeding success	No major obstacles expected to restrict further breeding success and release of the second-generation naked oat cultivars (replacing Lisbeth) into Finnish growing conditions.
	Economy	Hulls of conventional oat cause economic losses that naked oat lacks.
Threats	Availability	The only released naked oat cultivar Lisbeth does not attract farmers, while the modest success of it does not encourage the breeders to invest more on breeding naked oat. Low lot quantities dissatisfy industry.
	Production intensity	No substantial sign of increased interest and activity in growing naked oat, even though encouraging results and conclusions were gained during the National oat program (1998–2000).
	Seed production	Growing conditions in Finland limit the possibilities to have seed with high germination, which is a threat for stable and vigour seed markets. Legislative opportunities are not used to permanently reduce the germination requirement to 75%.

trix. To calculate a C ratio, we used 400 randomly generated matrices. The C ratio measures the coherence of the pairwise comparisons and therefore it is an important quality indicator of the SWOT analysis. As a general rule, a C ratio value of 10% or less is considered acceptable (Kurttila et al. 2000). This level was exceeded only once in the SWOT-analysis (Table 2). The consistency ratio of the comparisons among four SWOT groups was 0.4, 0.2 and 0.3%, when naked oat is produced for on-farm feed, the feed industry and the food industry, respectively. Hence, all these C ratios indicate that within and between group comparisons were made with adequate precision. All mathematical calculations were done using SAS/IML -software, version 8.2 (SAS 1999).

The local priorities resulting from SWOT-analysis are shown in Table 2. When growing naked oat for on-farm feed, nutritional quality was assigned the greatest strength, sensitivity to grain damage the greatest weakness, economy the greatest opportunity, and uncertainty in seed production the greatest threat. In contrast to this, when regarding the feed and food industries as potential targets for naked oat, the greatest weakness was incomplete expression of nakedness, the best opportunity, special niches, and the greatest threat one of unavailability, while the greatest strengths were high quality and storability. The factors from each SWOT-group with highest local priority were chosen to represent the group, they were compared to each other and their relative priorities calculated in parallel to the comparison of factors within each group (Kurttila et al. 2000).

All analyses were done separately for each end-use purpose, and they emphasised the feasibility of introducing naked oat first as on-farm feed crop. The subsequent possibility for enlarge-

Table 2. Priorities and consistency ratios for comparisons of the strength, weakness, opportunity and threat (SWOT) groups and factors when naked oat is produced for on-farm feed, and for the feed industry and food industry.

SWOT group	Priority of the group	SWOT factors	Consistency ratio, %	Priority of the factor within the group	Overall priority of the factor
Produced for on-farm feed					
Strengths	<u>0.335</u>	Experience in cultivation	1.2	0.158	0.053
		Adaptation to northern conditions		0.140	0.047
		Crop management		0.139	0.047
		Yielding ability		0.180	0.060
		Nutritional quality		<u>0.205</u>	0.069
		Storability		0.177	0.059
Weaknesses	0.116	Increased seeding rate	16.0	0.188	0.022
		Grain damage		<u>0.712</u>	0.083
		Expression of nakedness		0.100	0.012
Opportunities	0.241	Substitute for imported energy	0.3	0.337	0.081
		Targeted use (niches)		0.038	0.009
		Future breeding success		0.255	0.062
		Economy		<u>0.369</u>	0.089
Threats	0.309	Availability	8.2	0.443	0.137
		Production intensity		0.107	0.033
		Seed production		<u>0.450</u>	0.139

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Table 2. (cont.)

SWOT group	Priority of the group	SWOT factors	Consistency ratio, %	Priority of the factor within the group	Overall priority of the factor
Produced for feed industry					
Strengths	0.266	Experience in cultivation	5.9	0.168	0.045
		Adaptation to northern conditions		0.152	0.040
		Crop management		0.030	0.008
		Yielding ability		0.179	0.048
		Nutritional quality		<u>0.252</u>	0.067
		Storability		0.220	0.059
Weaknesses	0.193	Increased seeding rate	0.5	0.072	0.014
		Grain damage		0.377	0.073
		Expression of nakedness		<u>0.551</u>	0.106
Opportunities	0.241	Substitute for imported energy	1.5	0.283	0.068
		Targeted use (niches)		<u>0.311</u>	0.075
		Future breeding success		0.189	0.046
		Economy		0.216	0.052
Threats	<u>0.300</u>	Availability	0.8	<u>0.523</u>	0.157
		Production intensity		0.367	0.110
		Seed production		0.110	0.033
Produced for food industry					
Strengths	0.173	Experience in cultivation	6.5	0.160	0.028
		Adaptation to northern conditions		0.153	0.027
		Crop management		0.030	0.005
		Yielding ability		0.182	0.032
		Nutritional quality		0.235	0.041
		Storability		<u>0.240</u>	0.042
Weaknesses	<u>0.302</u>	Increased seeding rate	0.9	0.058	0.018
		Grain damage		0.388	0.117
		Expression of nakedness		<u>0.553</u>	0.167
Opportunities	0.249	Substitute for imported energy	0.04	0.046	0.012
		Targeted use (niches)		<u>0.395</u>	0.098
		Future breeding success		0.263	0.066
		Economy		0.296	0.074
Threats	0.276	Availability	0.05	<u>0.488</u>	0.135
		Production intensity		0.395	0.109
		Seed production		0.117	0.032

ment of production in the case of naked oat being well accepted, is likely to provide additional impetus for development of new-generation cultivars and stabilisation of seed markets with legislation to guarantee availability of naked oat in large quantities for possible future industrial use. Hence, SWOT-analysis proved to be a useful additional tool to aid decision-making. This is particularly the case when strategies are developed based on adequate published information. In such cases the analysis helped to prioritise positive and negative factors affecting conclusions and subsequent decisions. Using SWOT-analysis enabled formulation of a potential strategy to encourage better use of naked oat under Finnish growing conditions.

In conclusion, the literature review and the SWOT-analyses based on it indicated that naked oat is especially attractive as on-farm feed, where the major weaknesses, grain damage and incomplete expression of nakedness, do not prevent its use. The strength of naked oat is high nutritional quality, which outweighs both weaknesses and threats. Therefore, the most feasible strategy to enlarge the area of this under-utilised, high quality, energy-rich cereal crop is to introduce it first for on-farm use and later, if demonstrated to be successful, extend its production to industrial use.

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SELOSTUS

Paljasjyväinen kaura uutena viljelykasvina Suomen kasvuoloissa

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Paljasjyväistä kauraa viljeltiin Suomessa vain 285 hehtaarilla vuonna 2002, mikä on alle promille kauran viljelyalasta. Pieni viljelyala on seurausta useista epävarmuustekijöistä. Paljasjyväisyyteen kytkeytyy vahvuuksia ja heikkouksia. Tässä kirjallisuuskatsauksessa analysoimme paljasjyväisen kauran tuotannon vahvuuksia, heikkouksia, mahdollisuuksia ja uhkia nelikenttäanalyysin avulla (SWOT-analyysi).

Vahvuuksina esille nousevat pitkä kauran viljelykokemus, kauran ja paljasjyväisen kauran sopeutuminen Suomen kasvuoloihin, viljelymenetelmien samankaltaisuus tai niissä tehtävien muutosten toteutettavuus, hyvä sato, erinomainen laatu ja hyvä säilyvyys. Heikkouksiksi luokiteltiin tavanomaista kauraa suurempi kylvösiementarve (10 %), jyvän vaurioitumisherkkyys ja jyvien epätäydellinen kuoriutuminen. Mahdollisuuksina pidettiin paljasjyväisen kauran arvoa tuontienergian osittaisena korvaajana, soveltuvuutta erityiskäyttökohteisiin, kasvinjalostuksen mahdollisuuksia tuottaa Suomen kasvuoloihin sopeutuneita, nykyistä satoisampia lajikkeita ja alhaisempia tuotantokustannuksia (kuivaus, varastointi ja kuljetus). Uhkiksi koettiin epävarmuus saatavuudessa, alhainen tuotantointensiteetti ja siementuotannon epävarmuus.

Johtopäätökset arvotettiin kirjallisuuden perusteella, ja analysoitiin analyyttisen hierarkiaprosessin ja SWOT-analyysin yhdistelmällä. Koska vahvuuksien, heikkouksien, mahdollisuuksien ja uhkien painoarvot vaihtelevat käyttötarkoituksen mukaan, tehtiin analyysi erikseen käyttökohteen mukaan (kotoinen energiarehukäyttö, rehuteollisuus tai elintarviketeollisuus).

Analyysin perusteella kotoinen rehukäyttö osoittautui varteenotettavimmaksi ensivaiheen käyttökohteeksi, kun paljasjyväisen kauran viljelyä laajennetaan. Sadon hyvä laatu korvasi jyvän vaurioitumisen ja heikon itävyyden aiheuttamat menetykset. Paljasjyväisen kauransiemenen lisääntynyt kysyntä myös rohkaissee kasvinjalostajia kehittämään ja laskemaan markkinoille uuden sukupolven lajikkeita, joilla korvataan nykyisin ainoana lajikeluettelossa oleva heikkosatoinen ja pienijyväinen lajike. Vahvin rehuteollisuuden näkökulmasta esille noussut tekijä oli rajallinen saatavuus ja pienet tuotantoerät sekä elintarviketeollisuuden osalta jyvien epätäydellinen kuoriutuminen ja tämän johdosta rajalliseksi jäävä hyöty. Nämä tekijät ylittivät painoarvoltaan vahvuuksina esille nousseet erinomaisen laadun ja hyvän säilyvyyden sekä mahdollisuuksista erityiskäyttökohteet.