

UNIVERSITY OF HELSINKI
DEPARTMENT OF APPLIED BIOLOGY
SECTION OF CROP SCIENCE
PUBLICATION NO 37.

NORTHERN CHALLENGES FOR PROFITABLE PRODUCTION OF QUALITY NAKED OAT

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ACADEMIC DISSERTATION

TO BE PRESENTED, WITH THE PERMISSION OF THE FACULTY OF AGRICULTURE
AND FORESTRY OF THE UNIVERSITY OF HELSINKI, FOR PUBLIC CRITICISM IN
VIIKKI, AUDITORIUM B2, ON JULY 25TH, AT 12 O'CLOCK NOON.

HELSINKI 2008

Kirkkari, A-M. Northern challenges for profitable production of quality naked oat. University of Helsinki, Department of Applied Biology, Publication 37. Helsinki 40p. + appendices

Keywords: naked oat, germination, hull, husk, grain moisture, threshing, dehulled, trichomes, conventional oat, profitability, variable costs

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ISBN 978-952-92-3830-9 (printed version)

ISBN 978-952-10-4693-3 (PDF)

ISSN 1457-8085 (printed version)

ISSN 1796-6361 (PDF)

Cover picture: Designed by Kaija Laaksonen, TTS-Institute

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ABSTRACT

Naked oat (*Avena sativa f.sp. nuda* L.) is the highest quality cereal in northern growing conditions. However the cultivation area of naked oat is remarkably small even in those countries where the cultivation of conventional oat (*Avena sativa* L.) is familiar. Major challenges for naked oat production are to observe its nakedness. The caryopsis of naked oat is sensitive to mechanical damage at harvest, especially at high grain moisture content. The greater the grain moisture content of naked oat at harvest, the more losses of germination capacity was caused by threshing. For producing high quality naked oat seed, it is recommended that harvesting be done at as low grain moisture content as possible. However, if this is not possible, better germination can be ensured with gentle harvest by reducing the cylinder speed.

The greatest barrier to the use of conventional oat as an animal feed is its high hull content. In spite of its excellent fat and amino acid composition in animal feed use, as far as nutritional value is concerned, the total energy yield of oat is weaker than other cereals because of the hulls. Also with naked oat the dehulling is not complete, while hull content on different cultivars mostly varied between one to six percent. In addition to genotype, environmental conditions markedly control the expression of nakedness. Thresher settings had only limited effects on hull content. The function of hulls is to protect the groat, but this was confirmed only for Finnish, small grain, cultivar *Lisbeth*. Well germinating samples of *Lisbeth*, threshed at normal settings, contained higher hull percentage than those with low germination ability, while for cultivar *Bullion*, the protective effect of the hulls was not evident.

The oat kernel, caryopsis or groat, is generally covered with fine silky hairs termed trichomes. The trichomes of naked oat are partly lost during threshing and handling of grains. Trichomes can cause itchy reactions in those handling the grains. Trichomes also accumulate and form fine dust and can block-up machinery. The cultivars differed considerably in pubescence. Cultivars *Lisbeth* and *NK 00117* had most trichomes and *Bullion* fewest. For *Bullion*, some thresher settings, including increased cylinder speed, slightly increased grain polishing such that grains had some areas completely free of trichomes. Reduction of the concave clearance in the combine harvester had a similar effect. However, thresher settings did not affect the trichomes of *Lisbeth*. Adjusting thresher settings was generally not an efficient means of solving the problems

associated with naked oat trichomes, but cultivar differences existed and further efforts in breeding to reduce trichome numbers are needed.

The main differences in cultivation costs between naked and conventional oat lie in the amount of seeds required and the drying costs. The main differences affecting the economic result lie in market prices, yield level and feed value. The results indicate that naked oat is financially more profitable than conventional oat, when the crop is sold at a specific price at all yield levels, when the crop is used as feed at highest yield level. At lower yield levels, conventional oat is, in spite of its lower feed value, the more profitable option for feed use. Dehulled oat, however, did not achieve the same economic result as naked oat at any yield level, as the cost of dehulling, including disposing of the hull waste, was considerable.

According to this study naked oat can be cultivated successfully under northern conditions, when taking into consideration the soft, naked grain through cultivation chain. However, more plant breeding, agronomy research, and technological and political efforts are needed in order to promote and expand the cultivation of naked oat.

LIST OF ORIGINAL PUBLICATIONS

- I Kirkkari, A.-M., Peltonen-Sainio, P. & Rita, H. 2001. Reducing grain damage in naked oat through gentle harvesting. *Agricultural and Food Science in Finland* 10: 223-229.
- II Kirkkari, A.-M., Peltonen-Sainio, P. & Lehtinen, P. 2004. Dehulling capacity and storability of naked oat. *Agricultural and Food Science in Finland* 13: 198-211.
- III Kirkkari, A.-M., Peltonen-Sainio, P., Jauhiainen, L. 2008. Trichome numbers in naked oat cultivars. *Journal of Agricultural Science, manuscript*
- IV Kirkkari, A.-M. 2008. Comparative economic analysis for production of naked vs. conventional oat. *Acta Agriculturae Scandinavica Section B, Soil and Plant Sciences, in press*

1. INTRODUCTION

Finland is one of the world's northernmost grain producers and is a considerable oat producer: 3.5% of the world's oat (*Avena sativa* L.) is produced in Finland and the country has almost a 20% market share of the international oat trade (Ministry of Agriculture and Forestry 1998b, 2000). Oat grows well in the northern climate, particularly when dehulled, has a high energy content and numerous nutritional benefits. It has been estimated that oat can partially replace imported soybean, (*Glycine max* L. Merr.) (Ministry of Agriculture and Forestry 1998a). Oat is well adapted to a cool, humid climate and acidic soils. Furthermore, oat cultivation has a long tradition in Finland and growers are familiar with the required cultivation techniques.

Only cultivars adapted to the cool climate, short growing season and long days of Finland can be grown successfully. Such cultivars are not exceptionally rich in energy and protein. Oat grains have high fat content and well-balanced amino acid content. Unfortunately the hulls, which remain with conventional oat on the grain during threshing and have a nutritional value similar to that of straw, reduce the total energy value of oat considerably (Peltonen-Sainio et al. 2004a). Hulls represent over twenty percent of grain weight (Peltonen-Sainio 1997). Conventional oat must therefore always be dehulled before it can be used as food or as high-energy feed.

An alternative to conventional oat is naked oat (*Avena sativa* f.sp. *nuda* L.). In naked oat the lemma and palea are separated from the grains during threshing, and thus the naked grains are comparable with those of wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.). The lack of high-yielding naked oat cultivars has limited its cultivation in Finland. There are also some unfounded beliefs about cultivation and handling of naked oat that have restricted its cultivation. The cultivation methods for naked oat are exactly comparable with those for conventional oat, but there are certain issues that should be taken into account to ensure production of a top-quality crop. Since naked oat is a grain with a high fat content, the grain is rather soft and remains naked after threshing (Valentine 1995). This means that it has to be handled more carefully than conventional oat, particularly if the grain is moist (Peltonen-Sainio et al. 2001). Despite the name, naked oat is not completely naked, since often 1–3% of the hulls remain on the grains after threshing (Machan 1998, Kangas et al. 2001). Naked grains are also covered by fine hairs, trichomes (Burrows et al. 2001b), which are

partially lost during threshing and yield handling. The trichomes can cause considerable itchiness and create blockages in processing equipment.

In recent years, breeding has significantly improved the yield of naked oat and some cultivars already have yields comparable with those of conventional oat. At the same time the fraction represented by hulls has decreased. Plant breeding has resulted in a hull percentage of less than 1% at best. Furthermore, considerable effort in breeding is directed towards reducing the numbers of trichomes on the surfaces of the grains.

This study focuses on naked oat threshing and yield handling processes, with particular consideration being given to the moist harvest conditions typical for Finland. Through application of sound husbandry and adherence to the specific requirements for crop management, high quality yields of naked oat are possible under such challenging conditions. All the measures have to be based on sound economics and should lead to higher profits compared with conventional oat cultivation. This study therefore focused on comparing conventional and naked oat cultivation and use of the grain for different purposes.

2. LITERATURE REVIEW

2.1 Some specifications for naked oat cultivation

Oat is generally a marginal, secondary crop and its global cultivation area is modest compared with that for wheat and barley (*Hordeum vulgare* L.), despite the excellent nutritional and health features of the crop (Agriculture and Agri-Food Canada. 2006, Ministry of Agriculture in Finland 2007, Sveriges Officiella Statistik 2006). Even though oat requires less management and is an undemanding and relatively easy crop to cultivate, compared with other small-grain cereals, it has not increased in cultivation area. Oat also acts as a useful break crop for managing diseases in crops such as wheat and barley (Welch 1995).

During recent years, based on the results of strong research and development work, it has been confirmed that oat is not only a very suitable source of feed for many species of animals (Doyle and Valentine 1988, Valentine and Hale 1990), especially when hulls are absent, but it is also a grain with cholesterol-lowering effects for human consumption (Peterson 2004). The high hull percentage of oat, which normally ranges from 20–26%, but may be as high as 46% depending on the conditions, is the main obstacle to its use as feed (Welch 1995, Peltonen-Sainio et al. 2004a). The hulls increase the fibre content and decrease the digestibility and energy value of feed oat (Cudderford 1995). In spite of its excellent fat and amino acid composition for animal feed use, as far as nutritional value is concerned, the total energy yield of oat is inferior to that of other cereals since the hulls are similar in their nutritional value to straw. Thus the use and cultivation of oat has lagged behind that of other crops richer in energy.

Two thirds of Finnish oat production is directly consumed on farms as livestock feed. Oat would be a more valuable feed if it were not necessary to feed the hull. This could be realised with the cultivation of naked oat, or through on-site dehulling of conventional oat. Oat is dehulled in any case for food production, whether naked or conventional.

Cultivation of both conventional and naked oat requires a cool and moist climate. Almost all types of soil are suitable for growing oat, including acidic soils (Forsberg and Reeves 1995). Oat tolerates wet weather and acidic soils far better than wheat and barley, is relatively resistant to foliar diseases and requires fewer inputs of agrochemicals and fertilisers (Givens et al. 2004).

In Finland conventional oat has been the second-most cultivated grain crop after barley during recent decades (Ministry of Agriculture and Forestry 2007). Cultivation of naked oat is limited in Finland, partly because of the low yield potential of available cultivars and because of problems with germination and seedling emergence. However, new higher yielding cultivars are emerging elsewhere (Burrows et al. 2001a, Moudrý et al. 2004) and new handling protocols are helping to prevent the damage associated with germination problems (Peltonen-Sainio et al. 2001, Valentine 1995).

Because of the weaker sprouting of naked oat compared with the conventional type, it is recommended that a greater density of seeds is sown (Valentine and Hale 1990, Peltonen-Sainio 1997). Under Finnish conditions 550 germinating seeds per square metre is recommended (the recommendation for conventional oat is 500 seeds per square metre) (Peltonen-Sainio 1997, Peltonen-Sainio and Rajala 2001), whereas, according to Semudo (1999), in normal situations, a rate of 300 seeds per square metre for winter conventional types and 400 seeds per square metre for naked oat would be optimum rates, allowing for a spring plant population of 250 plants per square metre in Great Britain (Semudo 1999). Increasing the sowing rate from 400 to 790 seeds per square metre caused a significant increase in grain yield, both in naked and conventional oat in Poland (Stankowski and Świdzka-Ostapiak 2004). Using an average seed weight of 30 mg, Marshall et al. (1992) equated recommended seeding rates of 71.6–107.5 kg ha⁻¹ found in numerous US extension-type publications with 240–360 seeds per square metre.

Despite of the differences in number of seeds at sowing, cultivation techniques with naked and conventional oat are very similar. Fertilisation and plant protection can be managed in the same way for both crops. Compared with other cereal crops (barley, wheat, rye), oat often requires fewer pesticides and herbicides. Nevertheless, in some countries the economic effects of plant disease are already significant. For example, Wehrhahne (2004) reported that in Argentina, which can be considered to be a quite new oat producer, the most important problems for oat crops were rusts, especially crown rust (*Puccinia coronata*) in forage oat and stem rust (*Puccinia graminis*) in grain oat. Naked oat is generally more sensitive to herbicides than the typical hulled types (Marshall et al. 1992). On the other hand, the cultivation guides for conventional and naked oat do not suggest any limitations to the use of plant pesticides for naked oat (Oat in a new era, Naked Oat, Grower's note).

Nowadays some types of naked oat have already exceeded the groat yield of conventional oat (Moudrý et al. 2003). Burrows et al. (2001a) did not establish any significant difference between hulled and naked lines in oat 'rice' (oat groat) production. Doehlert et al. (2001) also reported that groat yield of the naked oat *Paul* was greater than groat yield of 11 other

conventional oat cultivars over 12 environments. In 2004 Moudrý et al. reported that, at standard output levels, production of hull-less grain yield (groat) was 23% higher in the naked than in hulled varieties in the Czech Republic.

2.2 The challenges in harvesting naked oat

2.2.1 Germination and the conditions at harvest

The caryopsis of naked oat, which threshes free from the husk (lemma and palea) during harvesting, is sensitive to mechanical damage at harvest, especially at high grain moisture content (Valentine 1995). Hulls are evidently important for successful germination and seedling establishment, protecting the groat from mechanical damage (Fulcher 1986, Peltonen-Sainio et al. 2001). Grain crops in Finland are often threshed when the moisture content of the grain is approximately 21–23% (Aaltonen et al. 1999) and dried directly to 14% grain moisture content to guarantee storability. The most vulnerable grains include those that thresh free from the lemma and palea, including those of wheat, rye and naked oat. The germination of unprotected naked seeds is easily reduced during threshing and may be further weakened during drying (Peltonen-Sainio et al. 2001, Järvenpää 1992).

Thornton (1986) studied the structure of various oat cultivars and their ability to withstand mechanical damage. However, no very resistant naked oat was identified. Moreover, naked cultivars differed in embryo protrusion, which may contribute to grain damage, but there was no solid evidence to suggest that less protruding embryos were associated with improved germination ability. Peltonen-Sainio et al. (2001) established no clear correlation between embryo protrusion and proportion of normal seedlings. Nevertheless, large and hard grains are likely to be more susceptible to mechanical damage (Thornton 1986, Peltonen-Sainio et al. 2001), since they are likely to hit the thresher surfaces with greater force than small grains (Valentine and Hale 1990).

Mechanical injuries, such as contusions, scratches and bruises, also reduce germination by making the grains vulnerable to fungal infections that reduce storability and hamper further processing (CIGR 1999). Some injuries reduce the viability of the grain immediately (e.g., embryo damage), while others only become evident later on during storage (Moore 1972).

Threshing and drying expose grains to mechanical stress and, therefore, threshing is often a delicate balance between minimising losses and producing high-quality grain. Grains are damaged particularly when a crop is threshed while moist. In the U.K. it is advised that naked oat should be threshed at grain moisture contents of less than 20% to prevent damage (Hayes 1992).

It is recommended that harvesting should be done at as low a grain moisture content as possible for producing high quality naked oat seed.

2.2.2 Thresher settings

It is not possible to obviate weather conditions occurring at grain filling and harvesting. According to Järvenpää (1992), wheat grain damage was reduced when threshed at high moisture content by adjusting the cylinder speed and concave clearance of the combine harvester. The implication of thresher settings can be marked. The higher the moisture content of the grain, the greater the impact of the cylinder speed on germination (Sitkei 1986, CIGR 1999). It is difficult to optimise thresher settings as increased cylinder speed is needed to free the grain from the lemma and palea and minimise threshing loss and grain damage at high moisture content (Arnold 1964). A minimum cylinder speed of 20–24 ms⁻¹ is required to thresh naked oat free from lemma and palea (Hayes 1992). This British guide to the cultivation of naked oat (Hayes 1992) suggests lengthening the threshing intervals as much as possible and reducing the speed of the threshing cylinder. Results from earlier research suggested that the cylinder speed affects germination, but Thornton (1986) showed that adjustment of concave clearance did not significantly affect germination of naked oat when a Hege plot combine harvester was used. Results from another study indicated that concave clearance should, however, be set as wide as possible (Valentine and Hale 1990). Under extreme conditions and with vulnerable grain cultivars, the quality of the crop usually deteriorates to a variable extent despite gentle threshing (Järvenpää 1992).

Good germination is essential if the crop is to be used as seed or in food processing that requires germination, such as malting (Oksman-Caldentey et al. 1999). Low germination rate does not, however, reduce the value of the crop as feed. When oat groat is damaged, the lipase enzyme becomes active and leads to the breakdown of fatty acids, thereby causing rancidity (Welch 1977). Since naked oat is far more susceptible to mechanical damage than conventional oat (Valentine 1995, Thornton 1986), it has been assumed to be also more prone to turn rancid (Peltonen-Sainio et al. 2004b).

2.3 Incomplete dehulling

The lemma of naked oat is thin and papery, unlike that of conventional oat, and contains only a little lignin, and the naked grain threshes free from the lemma similarly as for wheat and rye (Valentine 1995, Ougham et al. 1996). However, the dehulling of naked oat is not complete. Experiments carried out with naked oat in Finland showed that the hull content of different cultivars varied mostly between one and six percent, though some cultivars had hull contents as high as 13 percent (Kangas et al. 2001). The variation

in hull retention was earlier reported to vary greatly also elsewhere (Lawes and Boland 1974, Machan 1998). It is possible to increase the expression of nakedness through plant breeding. According to Kangas et al. (2001) late maturing cultivars may have a hull to grain fraction of less than one percent.

A single gene, *N-1*, controls how tightly the hull is attached to the groat (Kibite 2002). There are four main phenotypes of naked oat: completely naked, partially naked, partially hulled and completely hulled. Lawes and Boland (1974) reported that ten of 89 diverse naked genotypes grown in a field produced only fully naked grains. The mosaic phenotype produces a mixture of naked and covered kernels (Kibite 2002).

The attachment of the hull is physiologically associated with factors such as the lignin content of the lemma, the multiflorous character of the spikelet and the length of the rachilla. In the cultivars with mosaic expression of nakedness, the lignin content of the lemma also varies widely, thus causing some of the groat to retain the lemma, while others thresh free (Valentine 1995). The spikelet of naked oat is multiflorous, often carrying three or more fertile florets per spikelet, in contrast to conventional oat, which usually has two fertile florets (Valentine 1995, Doehlert et al. 2006). The florets that are set in the inflorescence at first have more time to mature physiologically and probably dehull better. Indeed, the grains retaining hulls are often from the least-advanced spikelets (Peltonen-Sainio et al. 2004b).

In addition to genotype, environmental conditions such as drought markedly control the expression of nakedness (Boland and Lawes 1973). Lawes and Boland (1974) found that naked oat grown in a greenhouse regularly produced more naked groat than one grown in the field. They concluded that temperature has a dominant effect on nakedness: at 25°C the expression of nakedness being complete in all cultivars studied, while at 20 °C some cultivars dehulled incompletely and at 15 °C only one cultivar expressed complete nakedness. Jenkins (1973) also reported that cool conditions prior to heading resulted in more hulled groat. According to Lawes and Boland (1974), the degree of nakedness of early-sown naked oat was higher than that of late sown. The possible reason for this was that the late sown oat developed under conditions more prone to higher temperature.

2.4 The trichomes on the grain surface

Many plants have hair-like outgrowths, trichomes, the significance of which in the life cycle of the plant is not always clear. In many species trichomes are believed to provide physical protection from predator attack (Johnson et al. 2002). Grains also have trichomes on their surface. The oat

kernel, also termed the caryopsis or groat, is generally covered with fine, silky hairs. Trichomes are also present at the non-embryo end of wheat, rye, barley, and triticale (*X Triticosecale* Witt.). They are collectively known as the “brush” and have a high silicon content (Evers et al. 1999).

The occurrence of trichomes is specific to different species and cultivars, but all oat cultivars have some trichomes on their grains. Yang Qingshou (2006) investigated the genetics of oat in 1981–1984, analysing more than 160 common varieties of mostly wild oat and classifying them into 21 different types. Practically all of the 21 types had spikelets with trichome-covered primary and secondary grains.

2.4.1 The function of trichomes

The protective value of the trichomes in grain may be insignificant. In fact, groat trichomes collect dust and pathogens (Forsberg and Reeves 1992), which is a negative feature. In conventional oat the trichomes are hidden by the lemma and palea. The oat trichomes do not emerge until the grain is processed at a mill or otherwise after dehulling. The trichomes of naked oat are partially lost during threshing and handling of the grains since the lemma and palea are usually lost and the surface of the grains is exposed to mechanical processes (Fulcher 1986). The trichomes can cause itchiness and even more serious reactions in those handling the grains.

The trichomes, as they accumulate and form fine dust, also block up grain processing machinery. The registration description of *Lamont* naked oat cautions producers about thin hairs that cause itchiness and notes that the hairs tend to block machinery (Erikson et al. 2003). Trichomes are clearly a disadvantage and growers are eager to have cultivars that lack them.

2.4.2 The possibilities for reducing trichomes

Scientists have searched for the genes affecting the number and length of trichomes (Burrows et al 2001b, IGER 2007, OMAFRA 2002). Burrows et al. (2001b) were the first to discover a single recessive gene, *Gt-1*, which reduces trichomes in naked oat. However, this gene had only a small effect on reducing the number and length of the trichomes at the brush end of the groat. Apparently another gene, yet unidentified, also controls the number of trichomes (Burrows et al. 2001b).

With the current naked oat cultivars, the trichomes are only partially removed during threshing. In order to have maximum trichome removal, the concave clearance of the thresher must be reduced (Valentine 1995). Usually the trichomes are removed by “polishing” the grain after threshing, especially when the grain is for human consumption (Valentine 1995).

2.5 Cultivation economics of naked and conventional oat

2.5.1 Variable costs in cultivation and harvesting

The cultivation of oat, conventional or naked, in Finland is in general more cost-effective than that of barley and wheat (Ministry of Agriculture of Finland 1998a). The weaker sprouting of naked oat compared with the conventional type means that a larger number of seeds is recommended for sowing. According to Peltonen-Sainio (1997) and Peltonen-Sainio and Rajala (2001), it is sufficient to increase the amount by 10% compared with conventional oat in Finland to have a similar seedling emergence rate as with conventional oat.

In countries where the grain does not dry sufficiently in the field, grain must be dried by blowing air through the grain mass. In Finland, more than 90% of crops produced are dried using warm air driers belonging to individual farms because the grain does not dry sufficiently in the field at such northern latitudes. For the fatty grains, like naked oat, it is recommended to dry grains to lower moisture content than for a grain such as wheat, which contains less fat. The electricity and fuel used to dry the grain increases total costs (Peltola 1997).

2.5.2 Yield and dehulling

When comparing the yield between naked and conventional oat, it is important that the comparison is based on groat yield (Peltonen-Sainio et al. 2004b). The grain yield of naked oat varied between 2.85 tha^{-1} and 7.66 tha^{-1} during the period 2001–2002 in Great Britain (Maunsell et al. 2004). At the same time the total grain yield for conventional oat varied between 5.37 tha^{-1} and 8.66 tha^{-1} (Maunsell et al. 2004). When conventional oat is dehulled (hull content 20–25 %), the groat yield of conventional oat is quite similar to that of naked oat. The yields for both conventional (4.9–6.1 tha^{-1}) and naked oat (2.5–4.3 tha^{-1}) were much more modest in Finland (Kangas et al. 2006).

The quality of naked oat is very similar to that of dehulled conventional oat (Peltonen-Sainio et al. 2004a). Hulls, that usually go to waste, make up 20–30% of the mass to be dehulled, but it can be as much as 50% if the batch of oat has not been sorted or the dehuller is not properly adjusted (Doehlert et al. 2004a, Hosney 1998, Weaver 1985). Oat mills frequently separate oat according to kernel size before dehulling to optimise milling yields (Doehlert et al. 2004b). There is a market for part of the hulls that otherwise go to waste, e.g. ground hulls are used as a raw material for some animal feeds (Ganßmann and Vorwerck 1995). The hulls are also used as bedding material and thermal fuel. When comparing conventional oat with naked oat, it is necessary to consider the higher processing costs caused by in dehulling, transportation and general handling of conventional oat during various phases of production (Peltonen-Sainio et al. 2004b).

2.5.3 Differences in feed value and market price

Oat is Finland's most oil-rich grain (Izákai, 2004). The oil content is double (43 g kg^{-1} DM, dry matter) that of wheat (19 g kg^{-1} DM) and barley (13 g kg^{-1} DM). Furthermore, the oil content of naked oat is double ($83\text{--}97 \text{ g kg}^{-1}$ DM) that of conventional oat (Valentine 1990). The nutritional properties of conventional oat, dehulled and naked oat in particular, are excellent. The composition of amino acids in naked oat is advantageous owing to the high content of lysine, methionine and cysteine (Welch 1995). Naked oat, which contains less poorly digestible fibres than conventional oat (Kempe et al. 2004), is a superior energy substrate for farm animals (Brand and van der Merwe 1996).

Unlike for wheat, barley and rye, the EU does not offer an intervention price nor maintain intervention stocks for oat (Agriculture and Agri-Food Canada 2006, Sveriges Officiella Statistik 2006, Ministry of Agriculture in Finland 2007). In the international grain market there exists a strong positive interdependency between the market prices for maize (*Zea mays* L.) and oat (Ministry of Agriculture of Finland 1998b, Oat Situation and Outlook, Nov 2005). This relationship was evident during the winter of 2007 when maize prices climbed following increased bioenergy demands. Oat prices also increased. The increasing use of maize and other grains for bioenergy (ethanol and biogas) will probably have an impact on the price of oat.

3. MATERIALS JA METHODS

3.1 Seed materials (I, II, III)

The seed materials used in these tests were cultivated in 1998–2000 and 2004 in southern Finland at the Experimental Farm of the Work Efficiency Institute, Rajamäki, at Viikki Experimental Farm of the University of Helsinki and at MTT Agrifood Research Finland, Jokioinen. In Rajamäki the field plots were sown and the yield threshed with standard farm machinery, while experimental machinery was used in Viikki and Jokioinen. Also most of the materials were sown in spring three times at 3–6 day intervals in order to achieve maximum variation in moisture content during threshing. The sowing density was 550/m² viable seeds per square metre for naked oat and 500 seeds per square metre for conventional oat as recommended by Peltonen-Sainio (1997). The field plots received a basal fertiliser dressing (90 kg N ha⁻¹, 18 kg P₂O₅ ha⁻¹, 41 kg K₂O ha⁻¹); weeds were controlled with a mixture of MCPA, dimethylamine salt (a.i. 450 g/ha) and triasulfuron (a.i. 4 g/ha) and aphids were controlled with dimethoate (a.i. 200 g/ha) as necessary.

Table 1. The field trials and measurements

Paper no.	Exp. years	Thresher settings			Cultivars studied	Main measurements
		standard	low cylinder speed	narrow concave clearance		
I	1998	x			Naked <i>Lisbeth</i> and <i>Bullion</i> , conventional <i>Salo</i>	Grain moisture at harvest %
	1999	x	x			
	2000	x		x		Germination%
II	1998	x			Naked <i>Lisbeth</i> and <i>Bullion</i> , conventional <i>Salo</i>	Grain moisture at harvest % Hull content (in weight) % Degree of hull retention % Germination %
	1999	x	x			
	2000	x		x		
	1998	x			Naked <i>Lisbeth</i> and <i>Bullion</i> , conventional <i>Salo</i>	Grain moisture at harvest % Fatty acid composition Protein content
	1999	x				
	II	1999	x			<i>Bullion</i> , <i>Lisbeth</i> , <i>Neon</i> , <i>Rhiannon</i> , <i>SW95926</i>
III	2004	x	x	x	Naked <i>Lisbeth</i> , <i>Bullion</i> , <i>Polar</i> , <i>NK00117</i> and conventional <i>Salo</i>	Pubescence
IV	2006–07	Analysis of variable costs				

3.2 Hull content and degree of hull retention (II)

The grain samples from 1998–2000 were analysed for the proportion of hulls remaining attached to the groat in three sub-samples weighing approximately 5 g each. The hulled groats were separated from the sample, dehulled by hand and the hull proportion of the total sample was weighed (hull content, %). In addition, the number of hulled grains per one hundred groats was counted for samples from 1999 and 2000 (degree of hull retention, %). The impact of degree of nakedness on groat damage (i.e., germination damage), hull content and threshing moisture content were measured across thresher settings and cultivars.

An additional set of experiments was undertaken to study the association between grain size and hull content. The samples of cultivars, *Bullion*, *Lisbeth*, *Neon*, *Rhiannon* and *SW95926* were sorted by hand into two groups: naked and retained hulls. In each cultivar the naked grains were weighed and sorted using sieve sizes of 1.7 and 2.2 mm. The grains

above the 2.0 mm sieve, above the 1.7 mm sieve, and below the 1.7 mm sieve were weighed and the grain size distributions (%) among these three size groups were recorded. Hulls retaining grains of each cultivar were first dehulled by hand and the resulting naked yield was sorted into three size groups and the proportion of each size group was determined as described above.

3.3 Grain moisture and germination (I)

Different thresher settings, including standard settings recommended for conventional oat, increased cylinder speed and reduced concave clearance, were used in the experiments. After each threshing round, a sample of approximately 3 kg of grain was taken from the tank of the combine harvester. To analyse the grain moisture, 10 g of whole grain was dried at 130° C for 19 hours. Control grain samples were gathered by hand from each plot before threshing and they were hand threshed after gentle drying. After harvesting, the samples were dried with cool air and the germination analyses were carried out approximately four months after harvesting. Germination analyses (4 x 100 seeds on blotting paper) were made at the Plant Production Inspection Centre, Loimaa, Finland. Germination, tested with four replicates, was classified as normal, abnormal or non-viable.

3.4 Storability (II)

Grain yield from two years, 1998 and 1999, of naked cultivars *Bullion* and *Lisbeth* and conventional reference cultivar *Salo*, were harvested at three to four moisture contents. In 1999 additional control samples were hand threshed to avoid any mechanical stress-induced grain damage caused by combine harvesting. Some 50 g of each sample (a total of 26) including only naked groat was analysed for protein content with a Kjeltec Auto 1030 Analyzer and fatty acid composition with gas chromatography after storing them at room temperature (20 °C) till September 2000 (i.e., yield 1998 for two years and 1999 for one year). Grain composition was analysed at MTT Chemistry Laboratory, Services Unit, Finland, using accredited, standardised methods. Volatile lipid oxidation products were determined essentially as described in Heiniö et al. (2002).

3.5 Pubescence (III)

The pubescence was studied in two experiments, the cultivar experiment and the threshing experiment. The cultivar experiment comprised five

cultivars, naked varieties *NK 00117*, *Polar*, *Lisbeth* and *Bullion* and the conventional variety *Salo*. This experiment comprised the same cultivars as the threshing experiment, with the addition of *NK 00117* and *Polar*. Each cultivar was sown in two 100 m² plots. The samples for the cultivar experiment were hand collected when the crops were fully ripe. Several bunches of panicles were collected evenly from each field plot. They were dried at room temperature in a well-ventilated room. Individual panicles from each bunch were selected for further study. A spikelet was selected from the top and from the bottom of each panicle. The lemma and palea were gently removed by hand, so the grain remained intact. The numbers of trichomes on the grains were determined under the microscope.

In the threshing experiment the threshing was carried out using standard farm machinery at three different thresher settings. Samples of threshed grain, which were at once free from lemma and palea, were examined under a microscope to provide a visual estimate of the pubescence of the grains and the impact of thresher settings on the numbers of trichomes.

3.6 Variable costs of cultivation and processing of oat (IV)

The data for the economic comparison are mainly based on information gathered from the literature and various statistics publications. In addition to this, a combustion test was carried out to measure the thermal values of oat. TTS Research, Natural Resources Department, Finland performed some preliminary combustion tests on oat in autumn 2005. The tests used 20–30 kW burners suitable for domestic use and appropriate boiler systems. The tests monitored the efficiency of the fuel in continual burning and compared it with that of wood pellets. Furthermore, laboratory analyses of combustion values were performed on the oat samples to be burned.

This study only looked at variable costs. The fixed costs are very dependent on events that a single farmer cannot usually influence, such as the structure of the farm and countryside, farm size, agricultural policy and national investment subsidies, co-operation between farms and between markets, and the market for agriculture products etc. This study concentrated only on comparisons of the variable costs.

In order to be able to assess the economic value of the yields, it is essential to know where and how the crop is being used, what alternative uses would be available for the yield and what the price is. When merely comparing variations in crop yield and production costs, an economic comparison is incomplete.

4. RESULTS AND DISCUSSION

4.1 Major challenges for naked oat production

4.1.1 Nakedness (II)

The function of hulls is to protect the groat (Welch 1995). A caryopsis covered by hulls is not as vulnerable to mechanical damage as a naked one, but the dehulling of naked oat is not complete. One of the five naked oat cultivars included in this study (II), *Neon*, had very low hull content (in weight). The hull content was less than 3% at its highest and cultivars *Lisbeth* and *Bullion* also had low hull content, ranging from less than 1% to 5%. *Rhiannon*, and particularly *SW95926*, exhibited high hull contents that approached 15%. This variation is also reported in the literature (Lawes and Boland 1974, Machan 1998, Kangas et al. 2001). The degree of hull retention changed in parallel with that of hull content. On average, a 10 percentage unit increase in degree of hull retention resulted in a 3 percentage unit increase in hull content (II).

When sorting the groats liberated from hulls during threshing into three size groups, some 33 to 48% of groats were above the 2.0 mm sieve, depending on cultivar (II). An exception was *Lisbeth*, for which only some 3% of its groat remained above the 2.0 mm sieve, since it has very small grains. When hulls retaining grains were dehulled by hand and sorted afterwards, groat size distribution was opposite to that found in groats liberated from hulls during threshing. Only 4–14% of dehulled grains remained above the 2.0 mm sieve (II). In general, also in conventional oat, the aim of sorting and pre-cleaning is to produce a lot with as even a size distribution as possible, to secure better dehulling properties in industry (Deane and Commers 1986).

There was variation in the hull content and degree of hull retention between the cultivars (II). *Lisbeth* seemed to be a mosaic cultivar (II), in which the lignin content of hulls varied highly (Kibite 2002) thus making its hull content non-responsive to even rough handling. It also had exceptionally small grains compared with the other cultivars studied. Not only did *Lisbeth* have very small grains, but it also had very high hull content (II). Hence, in cultivars other than *Lisbeth* and *Bullion* small grains tended to retain hulls more tightly during threshing. The most advanced grains were more completely filled and matured and therefore were also better able to dehull.

With naked oat the aim is to produce as completely dehulled grains as possible. The seeds without lemma and palea expose the trichomes on the grain surface (III). While the disadvantages caused by trichomes may seem insignificant, they can significantly affect growers' decisions on cultivar selection. The feather-like trichomes cause itchiness (Erikson et al. 2003), vary in number, are located on the surface of the grain in various patterns and vary in length. The length of trichomes ranges from 1 to 2.5 mm (III). The trichomes on the grain ranged from being well ordered to being completely tangled. The sturdiness of the trichomes also varied when visually estimated. Some trichomes were very thin and dusty while others were more robust.

In earlier studies cultivars showed considerable differences in the amount of trichome cover (Valentine 1995, Burrows 2001b, Erikson et al. 2003). The hairiest cultivars in this study (III) were the Finnish *Lisbeth* (test weight 62.7 and 1000 seed weight 27.9 g) and *NK 00117. Bullion* (test weight 68.6 and 1000 seed weight 29.5) had fewest trichomes. Completely trichome-free or polished grains were not recorded (III). The amount of trichomes did not seem to correspond to the grain weight or the test weight, although we found that *Bullion*, with the highest hectolitre weight, also had fewest trichomes (III), as demonstrated earlier by Burrows et al. (2001b).

The position of the grain on the panicle influenced the degree of pubescence (III). Grains from the base of the panicle had fewer trichomes than those from the apex of the panicle. There was also a clear tendency for fewer trichomes on tertiary and quaternary grains than on primary and secondary grains (III).

4.1.2 Grain moisture at harvest (I)

When the grain moisture content of naked oat at harvest increased, damage caused by threshing also increased (I). Threshing was considered to be the primary reason for reduced germination. When the grain moisture increased by a single percentage point, the germination of the naked oat cultivar *Lisbeth* decreased by 1.9% using standard settings in the combine harvester (I). At the same time hand-threshed control samples of all cultivars retained reasonably high levels of germination (100% to 86%) irrespective of grain moisture content at harvesting (I). Contrary to the report of Peltonen-Sainio et al. (2001), grains of conventional oat were also damaged when harvested at high moisture content, although the effect was less marked than with naked oat. A high germination percentage is however necessary only for seed material or if the grain is used in a process such as malting. For seed production, it is also possible to compensate for the reduction in germination by increasing the number of seeds sown (Peltonen-Sainio et al. 2001). When producing naked oat for feed, germination capacity is of no significance.

Grain moisture content at threshing had opposing effects on hull content and degree of hull retention depending on year (II). In a very dry year, 1999, the hull percentage of naked oat was high, whereas under the favourable growing conditions in 2000, the hull content was lower. In the growing season of 2000 the hull content was at its highest, but the proportion of hull-retaining grains was at its lowest. Growing conditions in 2000 probably favoured full and relatively slow ripening processes better than in 1999, when severe drought occurred and improved dehulling capacity (II). A similar observation was reported earlier by Lawes and Boland (1974). This means that the hulls remaining attached to the grains must have been heavy. High moisture content at threshing increased hull content in *Bullion*, but not in *Lisbeth* when standard thresher settings were used. However, in 2000 the degree of hull retention decreased as grain moisture increased (II).

There was no observable threshing moisture-content-induced variation in protein content of naked oat cultivars, *Bullion* and *Lisbeth*, or of the conventional *Salo*, when studying the effects of grain moisture content on grain composition after one (harvested in 1999) and two years (harvested in 1998) of storage at room temperature (II). Palmitic and oleic acid content was higher, while in cultivars *Lisbeth* and *Salo*, linolic acid concentrations were lower when hand threshed compared with combine harvested groat samples. No constant threshing moisture content effect on any of the measured fatty acid concentrations was recorded. There was a trend that in hand threshed samples of *Lisbeth* and *Salo*, saturated fatty acid content was less than that of combine harvested samples, independent of grain moisture content at harvest. In contrast, concentrations of unsaturated and polyunsaturated fatty acids were higher when hand threshed than when groat samples were combine harvested.

Major differences in production of volatile compounds were recorded between years, while far less was recorded among cultivars. Similarly to the findings of contrasting moisture content responses in fatty acid composition between years, production of volatile compounds in response to groat moisture at harvest was opposite in the two contrasting years. Moisture content at threshing was associated with concentrations of another groups of volatile compounds that most likely indicate degradation of amino acids or microbial and/or enzyme activity (II). In that case differences between years remained modest. The higher the grain moisture at harvest, the higher the concentration of isobutanal in *Bullion* in 1998 and *Salo* in 1999, isopentanal and 3-pentanone in *Salo* in 1999, and fenylacetaldehyde in *Bullion* and *Salo* in 1999.

4.1.3 Thresher settings (I, II, III)

Threshing a naked oat crop at a grain moisture content as low as possible can reduce harvesting damage. However, if this is not possible, better

germination can be ensured by reducing the cylinder speed. There was a tendency for germination to be maintained better at the lower cylinder speed (900 rpm, 21m/s), even under moist conditions (I). The impact of adjustments to thresher settings seemed to be higher with large (*Bullion*) rather than small grained cultivars (*Lisbeth*) (I).

Despite the recommendation that naked oat should be threshed using as wide a concave clearance as possible, it does not seem to affect markedly subsequent germination. Narrowing the concave clearance, from 18mm to 15mm at the front and from 7mm to 5mm at the rear, did not significantly affect germination (I). This was the case for all cultivars. This observation is supported further by earlier findings with naked oat (Thornton 1986) and wheat (Järvenpää 1992). A wide concave clearance does not represent a disadvantage as long as it does not affect the amount of grain threshed free of lemma and palea.

The postulated protective nature of hulls was confirmed only for *Lisbeth* (I). Well germinating grains of *Lisbeth*, threshed with standard settings, had a higher hull percentage than those with low germination ability, while for *Bullion*, the protective effect of the hulls was not evident. As reducing concave clearance did not decrease hull content, it did not affect germination capacity either (II). Low cylinder speeds, resulting in more gentle threshing and less mechanical stress, increased hull content in both cultivars with increasing threshing moisture contents. Reduced concave clearance increased hull content in *Lisbeth* and decreased that in *Bullion* as the threshing moisture content increased.

Thresher settings had only limited effects on hull content and degree of hull retention, contrary to the suggestion that gentle threshing increases the hull percentage (Thornton 1986, Valentine 1995, Peltonen-Sainio et al. 2001). High grain moisture at harvest resulted in decreased hull content and degree of hull retention in 1998 when the growing season was rainy and oat matured late. An opposite response was recorded in 1999 under constant drought, even though in both cases the aim was to harvest grains not earlier than at full mature (II).

After threshing, as after rough mechanical handling, *Bullion* grains had fewer trichomes than those of *Lisbeth*, as was also the case in the cultivar study (III). In the case of *Bullion*, an increase in cylinder speed slightly increased the polishing of the grains, so resulting in completely bare areas (III). Reduction of the concave clearance had a similar effect on increased polishing (III). Thresher settings did not affect trichome number of *Lisbeth* grains to the same extent as for *Bullion*. Grains of *Lisbeth* are narrow and small and thus even the removal of lemma and palea is difficult (II). Therefore, the grains of *Lisbeth* were not exposed to as rough mechanical handling as larger grains. It seemed that with standard threshing machinery, without any additional polishing equipment, complete removal of trichomes is impossible.

4.2 Major economic aspects of naked and conventional oat

4.2.1 The costs of cultivation (IV)

The cultivation costs for naked oat are almost same as the cultivation costs for conventional oat. The main differences between the cultivation costs for naked and conventional oat lie in the number of seeds required for sowing and the drying costs (IV). In comparison with other types of grain, savings in production costs can be achieved with oat in calcification and fertiliser use (Givens et al. 2004). Variable production costs are lower for oat than for other crops as oat is often grown as a low input crop on less productive land. Therefore activities such as chemical pesticide control may not be economically justifiable (Clifford 1995). Production cost calculations conducted by different advisory organisations in Finland show that the cultivation of oat is more cost-effective than that of barley and wheat (Ala-Mantila and Riepponen 1998). This is mainly because of the need for lower variable costs caused by disease control, calcification and fertilisation.

The only difference between naked and conventional oat cultivation is in the number of seeds required for sowing. The share of seed cost varied between 17% and 33% of total variable production costs in different countries, depending on recommendations for seed quantities and their seed prices (Green 2004). The 10%–30% higher seed quantity, which is recommended in different countries for naked oat in comparison with conventional oat, increased variable costs by 1.7% to 10%, depending on seeding rate (IV).

4.4.2 Differences in drying costs (IV)

It is recommended that naked oat is dried to a lower moisture content (12%, due to its high oil content) than conventional oat and other cereals. The higher the initial moisture level and the drier it becomes, the more oil (or other fuel) and electricity are consumed, both of which are significant variable costs (Peltola 1997).

In calculations of production cost (2005) on the website of the Northern Ireland Government, drying costs were calculated in two different ways. For farmers using their own drier, the cost of fuel to remove 5% moisture per tonne and the cost of electricity for fans and augers amounted to approximately €13.57, which equates with €2.71 per 1% of moisture removed. If a contractor is used for the drying, contract and handling charges are approximately €6.78/tonne, plus €3.77 per 1% of moisture removed. The variable costs of drying vary considerably depending on factors such as the size of the drying oven, the initial moisture content of the grain and the ambient air temperature. According to the machine cost calculation programme maintained by TTS Research, which is available

at <http://www.tts.fi>, the variable cost share of the removal of 1% moisture is an average of €2.60/tonne, irrespective of the size of the drier. This was calculated on the basis of starting values of 20m³ and 35m³ for driers, which take into account the drying time required for the removal of 1% of moisture and the oil, electricity and labour costs consumed during that time. According to the above, comparative calculations use a cost of €3/tonne for the removal of 1% of moisture (IV).

4.4.3 Yield, energy yield and thermal energy (IV)

When comparing the hull content and groat yields of conventional and naked oat in Great Britain and Finland, the groat yield of naked oat in Great Britain is already fully competitive with that of conventional oat, and even in Finland the groat yield of naked oat is catching up with that of the naked variety (IV).

The metabolisable energy (ME MJ kg⁻¹ DM) of naked oat for cattle feed varies between 13.9 and 15.0 MJ kg⁻¹ DM (Welch 1995, Kempe et al. 2001), while the corresponding values for barley are 12.8–13.6 (Valentine 1990). In terms of energy yield, wheat and naked oat exceed barley. Naked oat competes with barley and wheat even if its yield remains moderate, but the hectare-based energy yield of dehulled conventional oat is lower than that of barley owing to the significant loss of weight during dehulling (20%).

Of all cereals, oat seems to be the most suitable for burning, based on its high fat content, even though the hulls can cause problems in the combustion heads of burners (IV). When the thermal values for naked oat and conventional oat are compared, it is reasonable to assume that the values for naked oat should be considerably higher than for normal oat, due to the high fat content of the former. According to the combustion test results, the thermal value for both naked and conventional oat was similar (IV). Therefore no real price difference per tonne existed between the types of oat regarding heating capacity. Differences were based only on the total crop yield. Furthermore, it was noticeable that naked oat burned very poorly, much more poorly than conventional oat. Without hulls naked oat compacted more tightly than conventional oat and could have restricted oxygen circulation during the combustion process.

4.4.4 Dehulling costs (IV)

To get conventional oat at the same feed energy level as naked oat, it has to be dehulled. Dehulling generates variable and fixed costs for the machinery used, and also, to a certain extent, for labour costs. Nevertheless, the greatest cost is caused by waste represented by the hulls left over from dehulling, and other loose material resulting from the dehulling of the groat. Waste in industrial dehulling is calculated at 30% and at the farm level at 20%.

At the farm level dehulling can reach a capacity of 700–800 kg/hr. Usually the dehullers used at farms remove the hulls from the grain by

centrifugal force and impact against a rubber covered chamber wall minimising damage to the groat. After the impact dehulling, groats and hulls are separated by aspiration. At this level the machine costs for dehulling vary between €3.90/hr and €11.60/hr, depending on the volumes being processed. Furthermore, possible labour costs must be taken into account. The chain of work, however, can be automated to the extent that it demands human involvement for only a fraction of the operational time of the machine. In addition to machine costs, 20% waste must also be calculated as a cost. The hulls, in themselves worthless for animal feed, can instead be used as bedding material or as a thermal energy source.

4.4.5 Prices of oat (IV)

The price of oat has varied greatly in recent years, for example in Finland by as much as 38% between 2000 and 2005, with the direction always downwards along with the prices of other cereals (Cereals Co-Operation Group 2006). In most countries the price for oat is significantly lower than for barley and wheat (Forsberg & Reeves 1995). The price of oat at the beginning of 2005 in Germany was €103/t, in Sweden €96.69/t and in Finland €86.60/t (Ministry of Agriculture 2007). These prices are 5.8%, 6.8% and 17.8% lower than the prices for barley at the same time in the same countries (Ministry of Agriculture 2007).

The market prices for naked oat and conventional oat are different. Naked oat is 62% more expensive than conventional oat (Semudo 1999). Nevertheless, in Finland naked oat does not have a specific market price due to the limited market. The seeds are for sale in Finland and the price for a kilogram of naked oat is 60% higher than that for a conventional oat (wholesale price for seeds, spring 2007).

The greatest differences affecting the economics of oat production are based on the differences between market prices, the volumes of yield and higher feed values. The results indicate that naked oat is financially the more profitable option: firstly, when the crop is sold at a specific price at all yield levels, and secondly, when the crop is used as feed at the highest yield level. At lower yield levels conventional oat is, in spite of its lower feed value, the more profitable option for feed use (IV). Dehulled oat, however, did not produce the same economic result as naked oat at any yield level because the cost of dehulling, including disposing of the hull waste, was considerable.

5. CONCLUSIONS

Naked oat can be cultivated successfully under northern conditions, which are characterised by a cool growing season, long days and moist harvesting seasons. The extent to which naked oat loses germination capacity when threshed correlates with grain moisture content, although the impact can be reduced by lowering cylinder speed on the combine harvester. However, gentle threshing does not reduce the degree of hull retention, even though the resulting decrease in rough, mechanical handling might be assumed to do so. The degree of hull retention and hull content are more strongly linked to cultivar, consistency of grain size and weather conditions during the growing season. Another cultivar-related feature is the pubescence of naked oat. The pubescence decreased when more aggressive settings were used, i.e. cylinder speed was increased or concave clearance reduced. Still, the oat grain did not shed all its trichomes and thereby cease to provoke itching. By seeking to thresh naked oat as dry as possible and, if this is not possible, by adjusting the thresher settings as gently as possible, naked oat with high germination capacity can be produced for northern conditions. If germination capacity is not important for end-use, high-energy feed with good amino acid composition and good storability means naked oat can be produced even in years with moist threshing conditions.

From an economical aspect, despite the excellent nutritional benefits of naked oat, an absolute prerequisite for extending cultivation is to provide sufficiently high-yielding cultivars for the northern market. Comparison of crop yields and feed values, and inclusion of dehulling costs, hull loss and end-use of the yield invariably indicated that naked oat is the least expensive option. However, in addition to market forces having to be taken into account, it is essential to increase farmer interest in cultivating a novel crop such as naked oat.

Even though some of the challenges for expanding the cultivation of naked oat have been addressed, others require further research. Some of what has been resolved has been through cultivation technology, by taking into consideration the plant's physiological properties, and some through plant breeding. However, more plant breeding, agronomy research, and technological and political efforts are needed in order to promote and expand the cultivation of naked oat.

ACKNOWLEDGEMENTS

This work was mostly carried out at TTS Research, the Department of Natural Resources, in Rajamäki, Finland. The study was funded by the Ministry of Agriculture and Forestry, TTS Research and MTT Agrifood Research Finland, which I gratefully acknowledge.

I would like express my most sincere appreciation to my supervisor, Professor Pirjo Peltonen-Sainio, without whom this work would never have been completed. Pirjo's skill in guiding a researcher to understand things for herself is phenomenal, as is her ability to know when to step in and help in order to ensure that the work progresses. One of Pirjo's virtues is her boundless patience with her students.

I also want to thank Professor Pirjo Mäkelä for her excellent comments during my research and especially in the final phases. I am grateful for her patient answers and help in organising last-minute practical matters. Special thanks go to all the co-writers of my articles, lecturer in Statistics Hannu Rita, Chief Researcher Pekka Lehtinen and Biometrician Lauri Jauhiainen.

My sincere gratitude goes to my boss, Managing Director Tarmo Luoma, who tenaciously and understandingly maintained interest in the progress of my work throughout its long duration. His understanding also enabled me to complete this work almost entirely alongside my day job.

I would like to thank all my colleagues at TTS Research, especially those working in agricultural research who supported me during the whole process. I would like to thank Osmo Saarinen who managed our farm, and who meticulously took care of the practical arrangements for our field test. I would like to express my appreciation to Kaija Laaksonen who provided me with invaluable assistance whenever I needed it in getting acquainted with the subtleties of spreadsheets. I also am grateful to Jyrki Kouki and Kari Vuorio who performed combustion tests on oat even though it refused to combust. I would like to thank all those who have been trainers at TTS Research over the years and were put to work on various tasks concerning this itchy oat research. My sincere thanks go to Tapio Lahti, Research Director at the K –experimental farm, who kindly provided me with seeds for the field trials.

The original inspiration for this research came from my parents Anna and Veikko Hakala and our farm on Siippoontie. I would like to express my appreciation to my late father and especially to my mother who has supported me in this work as well as in every other aspect.

Lastly and most importantly I want to thank my family. My children Johanna, Jenna and Susanna have patiently understood the occasional blank stare on their mother's face, her deaf ears and her inexplicable loss of temper. My husband Hannu has compassionately encouraged me, listened to me and supported me throughout the process. Without your help and your support I would most likely have given up. Thank you for your love.

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