Vernon Burrows (signature)

PROCEEDINGS OF THE FOURTH INTERNATIONAL OAT CONFERENCE

VOLUME I

THE CHANGING ROLE OF OATS IN HUMAN AND ANIMAL NUTRITION

Edited by: Andrew R. Barr

October 19th, 1992

Hilton International Hotel

Adelaide, South Australia

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A Special Symposium sponsored by

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PREFACE

The Fourth International Oat Conference, of which these are the Proceedings, was held in Adelaide from 19th – 23rd October, 1992.

In the business meeting at the close of the Third International Oat Conference held at Lund, Sweden in 1988, the International Organising Committee under the chairmanship of Dr Robert Forsberg was elected to organise the next conference. Adelaide was chosen as the venue. The final date of the Fourth Conference and the outline of the program, including selection of the main speakers, were suggested by the International Committee but local arrangements and finalisation of the program were delegated to a local sub-committee comprising staff from the South Australian Department of Agriculture, the Australian Barley Board, the Uncle Tobys Company and the Australian Oat Breeders Group. I wish to record my appreciation of the work done by this local committee in assuming various organisational responsibilities over the three years prior to the conference.

The Conference was organised into two special symposia ("The Changing Role of Oats in Human and Animal Nutrition", "Wild Oats in World Agriculture"), two days of general sessions (Crop Protection, Molecular Biology, Breeding Methodology, Economics and Marketing, Cytogenetics/Genetics, Physiology, Forage) and a field tour of the Lower North district of South Australia.

The objectives of the symposium "The Changing Role of Oats in Human and Animal Nutrition" were:

1. review the current state of knowledge on the nutritional value of oats and their effects on human health.

2. present progress with naked oat breeding, commercialisation and marketing to reinforce the momentum of this emerging crop

3. establish the goals for breeding and processing oats in response to increasing sophistication and diversity of markets.

The Fourth International Oat Conference acknowledges the generous assistance from the following sponsors:

PREFACE continued

Special thanks to:

Sue Tasker, Tom Hoppo, and Dean Wardle:
for managing the oat breeding program during conference organising.

Geof Palmer: for efficiently managing finances as Treasurer

Dick Medd: for help, advice and encouragement in all aspects of the Wild Oats in World Agriculture Symposium.

Elisabeth Eaton: Principal of the Conference Secretariat (Festival City Conventions) for outstanding service and attention to detail.

Alan Dube: arranging sponsorship for delegates from Bulgaria, India, Czechoslovakia and Poland.

David Sparrow: liaison with the Crawford Agricultural Trust and Southern Foods to assist delegates from Bulgaria and Poland

From the outset there was a firm commitment to make the Conference as international as possible and every effort was made to provide a program that would attract participants from all parts of the world, from a wide range of scientific disciplines and the oat industry.

At the time of printing 100 full time delegates, 35 part-time, 2 students and 30 accompanying persons from 22 countries were registered.

I wish the next International Oat Conference every success in advancing the knowledge, production and quality of the oat crop.

Andrew R Barr
Chairman
Fourth International Oat Conference, Inc.

The Changing Role of Oats in Human and Animal Nutrition

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The Changing Role of Oats in Human and Animal Nutrition

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Review of the Effects of Oats on Human Health

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Summary

Consumption of oats for improvement of health has a strong historical basis. Recent research has identified active components within oats that are associated with specific health benefits such as lowering blood lipids, regulating blood glucose, and protecting against tumor development in the colon. The most well-documented effects of oat consumption have been attributed to the soluble fiber fraction beta glucan. Oats also contain a high proportion of monounsaturated fat, antioxidants such as tocotrienols, and an amino acid profile rich in arginine relative to lysine. Each of these components has also been associated with specific physiological effects that should favorably impact health. This paper will describe the health benefits of oats contributing to reduced risk of the major chronic degenerative diseases of industrialized countries. The active component responsible for each effect and the potential mechanism of action will be discussed. Future research directions in this area will also be identified.

Significance of oat composition to human physiology

Cereal grains have been cultivated for consumption by human populations for about twenty thousand years as farming began to replace hunting and gathering as a means for obtaining food[56]. Human biological systems are believed to have evolved over most of the course of time with plant-based foods comprising from 65% to 90% of the total diet[27]. Although early humans probably ate substantial amounts of meat, the quality of this meat was similar to wild game which is leaner and thus richer in protein than most meats consumed today. And in contrast to modern dietary patterns, meat consumed by early humans was accompanied by intake of large amounts of dietary fiber. Daily intake of dietary fiber during the late paleolithic age is estimated to have been approximately 46 grams[27].

The high prevalences of the chronic degenerative diseases such as cardiovascular disease, cancer, and diabetes which are observed in industrialized countries are believed to result as much from inadequate consumption of fiber-rich grains, fruits, and vegetables as from excessive intake of high fat animal foods[93]. Population subgroups such as vegetarians who reside within these countries but who have maintained a predominantly plant-based diet have prevalences of chronic diseases which are lower than expected based on what is observed for the rest of the population and which are comparable to those observed in primitive societies where this type of dietary pattern has never been abandoned[8,27,81].

Recent studies have strengthened support in favor of health benefits associated with consumption of grains and other plant foods through identifying and isolating the active components within these plants, establishing their biological effects on human physiology and metabolism, and examining changes in prevalence of disease or in levels of markers for diseases (such as serum cholesterol for coronary heart disease) associated with consumption of these foods by human subjects. From this body of research, favorable effects on human health have been identified for a number of components of oats. The greatest amount of work to date has been on the lipid-lowering effects of the oat soluble fiber beta-glucan[104]. However, the high proportion of monounsaturated fat in oat lipid may also provide potential benefits since several studies have indicated that this type of fat may favorably influence blood lipids[16], blood pressure[92], and energy balance[64]. Oat lipid is also rich in the antioxidant tocotrienols (83). Antioxidants have been linked to reduced risk of cancer, heart disease, and degenerative changes in the eye as well as to increased immune function[9,13,23]. Oat protein may also be beneficial to health as a result of an amino acid profile which has been shown to favorably influence blood lipids[59].

Effect on blood lipids

The most well-documented benefit of oat consumption on human health is its effectiveness in lowering blood total cholesterol and LDL-cholesterol. The large volume of research on this subject spans a period of almost 30 years. The first observation that oat consumption might cause a decrease in serum cholesterol in animals and humans was reported by de Groot and coworkers in 1963[21]. Since that time, more than 30 studies with human volunteers have been completed[2,3,5,6,12,15,20-22,32-34,36,48-52,55,57,63,70,78,84,86,89,90,94,96-98,102,106] The majority of these studies have found that when consumed in reasonable amounts of 28 to 56 g daily (an average of 1 to 2 servings) either as a cereal or as an ingredient in breads or muffins, serum cholesterol is decreased by a magnitude ranging from 3% to 19% for those with high baseline levels[2,3,5,6,20-22,32-34,36,48,49,52,55,70,78,84,86,94,98,106] and by smaller amounts of 0-7.5% for those with normal baseline levels[32,57,84,90,96,97]. LDL-cholesterol, which is even more strongly associated with risk of cardiovascular disease than total cholesterol, showed a decline ranging from 3% to 16% in the majority of the studies where this cholesterol fraction was measured[2,3,5,6,32,49,52,55,90,94,96-98]

An important additional consideration about the lipid-lowering effect of oats is that the protective fraction of HDL-cholesterol does not consistently decrease with the decrease in total cholesterol as has been frequently observed with other lipid-lowering regimens. A number of studies have actually found an increase in HDL-cholesterol with oat consumption[20,33,48,52,96,97]. This increase in HDL together with the decreases in LDL and total cholesterol observed with oat consumption should result in an even more favorable risk profile for cardiovascular disease through lowering the ratio of LDL to HDL. Although the oat-induced decrease in total cholesterol has been called modest by pharmaceutical standards, the impact on public health is still considerable. In the U.S., it has been estimated that a decrease of 1% in serum total cholesterol would result in a decrease in 2% of the approximately 500,000 deaths resulting each year from coronary heart disease[66,67].

Oat consumption was found to lower cholesterol in both adult men and women ranging in age from approximately 20 to 70 years old whether or not they had elevated cholesterol at baseline. However, the largest decreases in cholesterol were observed for those who had the highest baseline cholesterol levels or those who are at the highest risk for coronary heart disease[84]. The effect of oat consumption appears to be due specifically to the inclusion of oats in the diet rather than to replacement of foods high in fat and cholesterol with oat-based foods lower in fat[84]. Because dietary fat has the most powerful impact on blood lipids of any dietary factor, the effects of such a substitution would have to be accounted for before the effects attributable specifically to oat consumption can be assessed. In studies where diets were reduced in total fat, saturated fat, and cholesterol for six weeks prior to beginning the oat intervention, serum cholesterol was further reduced following addition of oats to the diet[20,96-98].

The cholesterol-lowering benefits of oats have been attributed almost entirely to the presence of beta-glucan in the oat fiber fraction. A number of animal studies have identified this compound as the active component of oats which is associated with the reduction in serum cholesterol[10,28,101]. A regression analysis of the combined results of 10 well-controlled studies in free-living adults revealed that an oat intake equivalent to approximately 3.0 g of beta-glucan should result in a decrease of 5% in serum cholesterol [5,6,20,22,32,51,52,97,98,Beling,unpublished data]

In addition to the soluble fiber fraction of oats, the protein fraction may also contribute to the cholesterol-lowering effect observed with consumption of this grain. Kritchevsky and colleagues[59] have reported that consumption of plant protein or amino acid supplements providing a high ratio of arginine to lysine was associated with a decrease in cholesterol in human subjects. Although oats have not been directly tested in this regard, the ratio of arginine to lysine in oat protein is 1.8 compared to the ratio of 0.45 in the milk protein casein. Welch et al[101] reported a moderate cholesterol-lowering activity for the oat protein fraction compared to the gum fraction in chicks.

Effect on blood glucose regulation

Interest in the possibility that oat consumption may impact regulation of blood glucose was stimulated by studies reporting lower blood glucose and insulin levels in diabetics and nondiabetic subjects consuming high carbohydrate-high fiber diets[1,4,43,53]. These diets were also found to increase sensitivity of peripheral tissues such as skeletal muscle to the effects of insulin thus contributing to better blood glucose control[31]. Decreased insulin sensitivity is believed to play an important role in the decrease in glucose tolerance and increases in serum lipids and blood pressure observed with age[31,74].

Oat bran and oatmeal supplementation studies have yielded results showing effects on blood glucose regulation similar to those observed with high carbohydrate-high fiber diets. Oats appear to have a more favorable effect on blood glucose and insulin responses than other cereal grains such as wheat or corn[44]. The effectiveness of oats in regulating blood glucose levels is not diminished by processing since similar responses were seen whether whole groats, rolled oats, or oatmeal were consumed[35]. In contrast, the effectiveness of wheat in regulating blood glucose diminished with the degree of processing from whole grain to cracked grain, coarse flour, and fine flour.

The viscosity of oat beta-glucan has been implicated as the factor responsible for the favorable effect of oats on blood glucose[105]. The proposed mechanism for the soluble fiber effect may involve a slowing of nutrient uptake in the small intestine through effects on delayed gastric emptying[37], assimilation of carbohydrate by digestive enzymes[25,79], altered intestinal motility with increased thickness of the unstirred water layer[25,30], and impedance of nutrient diffusion[46]. The blood glucose response to a food has been found to correlate better with the soluble fiber fraction than with the total dietary fiber[77] which may explain why blood glucose levels are lower after consumption of oats than either wheat or corn.

The addition of oat gum containing 80% beta-glucan to a wheat-based cereal resulted in a lowering of blood glucose levels in noninsulin-dependent diabetics by 50% compared with the unsupplemented cereal (Braaten, unpublished data). Oat bran with 15% beta-glucan lowered blood glucose by 40%. Not only were blood glucose levels lower, but the time period before the peak glucose levels were achieved following consumption of the wheat cereal was also delayed by 40 minutes with the addition of either oat gum or oat bran. Although other sources of soluble fiber such as guar gum are also effective in blunting the blood glucose response, oat gum appears to be tolerated better by human subjects[11].

The delayed blood glucose response and lower peak levels observed following consumption of oat bran or oat gum compared with wheat suggests that carbohydrate is released at a slower rate from the oat source and thus blood glucose levels should be maintained above fasting levels for a longer time period. The possibility that this effect might confer a metabolic advantage for performance of physical and mental tasks has been suggested and is an area of current active research interest. Improvement in physical endurance has been reported when blood glucose levels were maintained by ingestion of carbohydrate during exercise[17]. Cognitive performance may also be affected similarly[87].

The onset of fatigue is believed to be triggered by several physiological responses resulting from a rapid insulin response to carbohydrate that is quickly absorbed[5]. One of these responses is a rapid clearance of glucose from the blood which in turn depletes the tissues of a source of metabolic fuel. Another involves the increased rate of uptake of the amino acid tryptophan by the brain for the production of the neurotransmitter, serotonin. Serotonin has sedative-like effects on the central nervous system[107]. Increased levels of this neurotransmitter at a time when blood glucose levels are falling could promote the early onset of fatigue and diminish performance. Consequently, soluble fiber from oats which should moderate the insulin response through delaying glucose absorption, should delay the onset of fatigue and thus enhance performance[46].

Effects on weight control

The utility of high fiber diets for promoting weight loss is an area of burgeoning research interest which appears to be promising. Significantly greater weight losses were

demonstrated in two double-blind placebo-controlled trials where moderately obese women consumed 5 or 7 g fiber supplements at two levels of reduced caloric intake[85]. Oat bran incorporated into biscuits to provide 5 g of total fiber daily resulted in average weight losses of 16 kg in women and 11 to 14 kg in men over periods of about a year[60].

An additional advantage of the oat supplementation was that fewer subjects in this group dropped out of the study than in the group taking a fiber supplement suggesting that the long-term compliance needed to achieve meaningful weight loss may be more readily accomplished with oats incorporated into foods.

Most of the evidence suggesting an effect of fiber on weight loss indicates that soluble fiber is more effective than insoluble fiber in this regard[65]. The proposed mechanisms through which high fiber foods may affect energy intake involve alterations in metabolic variables that are more responsive to soluble fiber intake than to insoluble fiber[65]. Among these are a delay in absorption of nutrients which alters secretion of gut hormones, decreases metabolic rate, and promotes fecal energy losses. Delayed gastric emptying by viscous fiber could also result in a feeling of fullness that decreases food intake. Ratings for hunger were lower among subjects consuming oat bran biscuits as part of a weight reduction diet compared with controls given a fiber supplement[60].

Effect on colon cancer

The relationship between oat consumption and colon cancer is not well understood. Several epidemiological studies have specifically identified an inverse association between consumption of cereals and risk of colon cancer[8,24,72]. This protective effect of cereal grains has been attributed to the dietary fiber component, but the findings from some case-control studies that estimated fiber intake from questionnaires are conflicting[42,73]. The association of fruit and vegetable intake with low prevalence of colon cancer suggests that fiber may be a protective factor[62], but other components such as antioxidant vitamins or other plant-derived chemicals may also be involved[99].

Among the mechanisms proposed to explain the benefits of dietary fiber on tumor development in the colon are fecal bulking, which dilutes carcinogens and bile acids[71], and reduced transit time, which decreases bacterial conversion of procarcinogens to carcinogens and reduces contact time between carcinogens and lumenal mucosal cells[88]. Because insoluble fiber from sources such as wheat or corn is a more effective fecal bulking agent than is soluble fiber from oats, and appears to have a greater impact on reducing transit time[19,26,65], it has been suggested that the insoluble fraction of grains may have a greater impact on reducing risk of colon cancer than the soluble fraction.

However, recent studies have indicated that the colon might also protected from tumor development by soluble fiber as a consequence of fermentation to short chain fatty acids by gut microflora[82,100]. Among the end products of microbial fermentation of soluble fiber is butyrate, a short chain fatty acid which is a preferred substrate for metabolism by colonocytes[7]. Butyrate has been shown to inhibit the growth of human adenocarcinoma cell lines in vitro[18,54], possibly through promoting mechanisms for DNA repair[61]. The presence of butyrate and other short chain fatty acids in the colon also results in a decrease in pH which has been found to inhibit bacterial conversion of bile acids into potentially carcinogenic secondary compounds[91]. Fecal pH has been associated with inhibition of development of malignant colonic tumors in animals and with decreased risk of colon cancer in humans[82].

The results from a few studies in animal models have suggested that soluble fiber from several sources may stimulate the rate of colon cell proliferation[40,47], but the significance of this effect to tumor development is not understood[38,47,69]. The pattern of increased cellular proliferation observed when colon cells were exposed to sources of soluble fiber in experimental animals might resemble a preneoplastic stage of cell growth[68], but the possibility that these changes in cellular proliferation rates could reflect a role for dietary fiber in regulation of mucosal cell growth has also been raised[39]. The effect of oat bran and other sources of soluble fiber, pectin and guar gum, on colon cell proliferation was tested in rats[41]. Although this study found indications of a possible adverse effect, these findings have been questioned because oat bran was fed at very high levels and because

the suitability of the rat as a model for examining effects of diet on colon cancer has been criticized on several grounds[45,76].

Further studies are needed to clarify the apparently contradictory findings regarding oat consumption, its effects on colonic proliferation patterns, and the relationship of these effects to tumor development.

It would appear reasonable to assume that these relationhips will ultimately prove to be favorable. Oats contain several components believed to be protective for the colon. In addition to the fermentable soluble fiber component and high yield of butyric acid obtained from oats, the antioxidant properties of the tocotrienols and phenolic compounds present in this grain should favorably impact the colon resulting in inhibition of tumor development. Antioxidants are considered to be among the important anticarcinogenic substances identified in plants[23,103]. It would also appear from international comparisons that oat consumption will prove to be beneficial for reducing risk of human colon cancer when consumed in physiological amounts. These comparisons have found that in countries where dietary patterns are associated with a low prevalence of coronary heart disease, prevalence of colon cancer is also low[80].

Implications of research findings for increased oat consumption

The dietary recommedations of several major public health agencies in the United States are currently emphasizing a greater consumption of grains. The recent pyramid developed by the U.S. Department of Agriculture to replace its Basic Four Food Group approach for achieving a balanced diet targets grains as the base for the diet[95]. Six to eleven servings daily are recommended from this food group. This emphasis towards a grain-based diet is consistent with the diets believed to be consumed by early humans and which when consumed by modern humans are associated with the lowest prevalences of chronic diseases. Oats should be showcased within this framework because this grain has health benefits that address each of the major chronic diseases of industrialized nations: coronary heart disease, cancer, and diabetes. And based on preliminary findings to date from ongoing research, oats might also provide benefits for blood pressure and weight control in the future.

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Oat Product Consumption for the Treatment of Hypercholesterolemia

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Summary

Present evidence strongly supports the hypothesis that the incorporation of oat products into the diet will effect a modest but statistically significant reduction in blood cholesterol. This effect will be more pronounced in persons with higher initial cholesterol levels. The consumption of oats should be considered as one component in the first line treatment of hypercholesterolemia.

Introduction

Research over the past thirty years has yielded a substantial amount of information that supports a recommendation for consumption of oat products as part of a first line intervention against hypercholesterolemia. Throughout the 1980s Anderson *et al* performed several metabolic ward trials with male hypercholesterolemic subjects, each of which supported the association between consumption of oats and reduction in blood cholesterol.[1-5] Van Horn and her colleagues performed three large randomized, controlled clinical trials and reported similar findings in over 500 free-living subjects.[6-8] These results were further supported by two large, randomized, controlled trials that compared the effects of oat product consumption to that of wheat products.[9,10] Several smaller trials have also been published, most supporting the cholesterol-lowering effect of oats, but a few reporting either equivocal findings or the absence of an association.[11-22] One of these, a randomized, controlled, 20-subject trial that compared the consumption of oat bran to a comparable amount of wheat bran, received much notoriety by concluding that the two grains lowered blood cholesterol to a similar degree.[11] The authors further postulated that the cholesterol reduction was the result of a substitution of carbohydrates for dietary cholesterol and saturated fat. This study created a great deal of confusion about the role of oat products in a heart-healthy lifestyle.

To settle the controversy, a meta-analysis, a systematic qualitative and quantitative summary of the results of several independent trials, was performed to determine whether the evidence derived from studies of freeliving subjects supports the hypothesis that oat product consumption can lower blood cholesterol.[23]

Methods

Raw data sets of both published and unpublished studies performed throughout the world were solicited, and 70 percent (14 of 20) were received (Table 1). For the remaining studies, necessary information was gleaned from the published reports. Ten trials met an *a priori* criteria for quality that stated the trials must have been randomized and controlled, and monitoring both dietary and body weight changes for treated and control subjects must have occurred. The data from these 10 trials formed the basis for the quantitative analysis; the meta-analytic techniques of DerSimonian and Laird were used to calculate a net effect size (change in blood total cholesterol of treated subjects after accounting for changes in control subjects) and associated p-values.[24,25]

Metabolic ward trials and trials of free-living subjects have demonstrated that reductions in blood total cholesterol with oat consumption are primarily a result of a reduction in low-density lipoproteins; high-density lipoproteins and triglycerides remain essentially unchanged.[3,6-10,22] The variable of interest for the meta-analysis was blood total cholesterol, however, because not every trial measured changes in lipoproteins.

Results

The net change in total cholesterol in treated subjects was -0.13 mmol/L (-5.9 mg/dL) (95% confidence interval: -0.19 to -0.017 mmol/L; -8.4 to -3.3 mg/dL). When the amount of oat product consumed (measured in grams of soluble fiber) and the initial cholesterol level of subjects were considered, a significant (p=0.048) interaction was found: Trials in which subjects consumed at least 3 grams of soluble fiber from oats and had initial cholesterol levels of 5.9 mmol/L (229 mg/dL) or higher demonstrated a five-fold greater reduction in total cholesterol than trials in which subjects consumed less soluble fiber from oats and had lower initial cholesterol levels (Table 1). This finding helped explain the negligible effect of oats in the trial of Swain et al; the mean initial cholesterol level for the 20 subjects was just 4.8 mmol/L (186 mg/dL).[11]

Table 1.   Trials of Free-Living Subjects Reviewed for the Meta-Analysis

Study	Design	Intervention	Change in Blood Total Cholesterol
Davidson et al [10,a,b]	Parallel, 6wk phase; All subjects on a low-fat, low cholesterol background diet	28g, 56g, 84g OB or OM cereal (n@ 20 each group) v 28g WB cereal (n=20)	28g OB: - 4% 57g OB: -10% 84g OB: - 7% 28g OM: - 4% 57g OM: - 3% 84g OM - 8%
Demark-Wahnefried et al [14,a]	Parallel, 12 wk phase;	Low fat diet + 50 g OB (n=18) v Low fat diet only (n=15) v usual diet + 50 g OB (n=15) v usual diet + 42.5 g processed OB (n=20)	No support for association between oat consumption and reduction
Gold and Davidson[20,a,b]	Parallel, 4 wk phase;	34 g OB muffins (n—19) v 1/2 OB 1/2 WB muffins (n=28) v 34g WB muffins (n=25)	34g OB: -5%
Hegsted et al [16,a]	Cross-over; 3wk phases	100g OB v 100g rice bran (n= 11 subjects)	-7% (OB)
Keenan et al [9,a,b]	2 X 2 cross-over, 6 wk phases; All subjects on a low-fat, low cholesterol background	57 g OB cereal (75 subjects crossed) v 57 g WB cereal v AHA diet alone (n= 67)	OB compared to WB: -2% OB compared to low-fat diet only: -8%
Kestin et al [21,a,b]	3 X 3 crossover, 4 wk phases; All subjects on a low-fiber background diet	95g OB bread v 35g WB bread v 60g rice bran bread (24 total subjects)	OB compared to WB: -5.5%
O'Brien et al [15]	Parallel, 18 day phase; All subjects on a high-complex carbohydrate background diet	50g OB supplement (n=15) v 50g WB supplement (n=15) v Controls (n—15)	No support for association between oat consumption and reduction
O'Kell and Duston[12]	Sequential periods; 3 months on oats, 3 months off oats	1/2 cup females, 2/3 cup males, dry uncooked oats (n= 45)	No support for association between oat consumption and reduction
Reynolds et al [19]	Parallel, 4 wk phase; All subjects on a low-fat, low cholesterol background	24g OB cereal v 84 g corn cereal (total n—43)	-4%

Table 1. continued

Storch et al [17]	2 X 2 cross-over, 6 wk phases	53g OB muffins v 53g WB muffins	-7%
Swain et al [11,b]	2 X 2 cross-over, 8 wk phases;	100 g OB entrees, muffins (20 subjects crossed) v 100g WB entrees, muffins	No support for association between oat consumption and reduction
Turnbull and Leeds[22,a,b]	2 X 2 cross-over, 4 wk phases; All subjects on a low-fat, low cholesterol background	OM 150g OM porridge/biscuits v 150 g WB biscuits	-5%
Van Horn et al [7,a,b]	Parallel, 6 wk phase; All subjects on a low-fat, low cholesterol background diet	57 g OB cereal/muffins (n= 69) v 57g OM cereal/muffins (n=69) v Diet controls (n=70)	-5% (OB v diet) -6% (OM v diet)
Van Horn et al [8,a,b]	Parallel, 6 wk phase; All subjects on a low-fat, low cholesterol background diet	57g OM cereal/muffins (n=113) v Diet controls (n—123)	-4%
Van Horn et al [9,a,b]	Parallel, 8 wk phase	57 g OM cereal (n=42) v Usual diet controls (n=38)	-5%
S.Beling [a,b,c]	Parallel, 4 wk phase	Low-fat, low cholesterol diet + 40g OB (n= 119) v Usual diet + 40g OB (n= 137) v Control group (no special diet, no OB product) (n= 91)	-2%
F. Thye [a,c]	Parallel; 9 wk phase; All subjects consumed oat products; half of subjects also incorporated exercise into their regime	100 g OB (n= 12) 100g OM (n= 11)	-6% (OB) -16% (OM)

Abbreviations: OB — oat bran; OM = oatmeal; WB = wheat bran; Wk = week
a: Raw data received
b: Met a *priori* inclusion criteria for quality; was included in the quantitative analysis
c: Unpublished study; data received from principal investigator

Keys Scores were calculated for seven of the trials to address the contention that reduction in blood cholesterol could be occurring as a result of a substitution of oats for dietary cholesterol and saturated fatty acids. Keys Scores can provide an estimate, under isocaloric conditions, of the amount that blood cholesterol would be expected to change when known ch anges occur in the intake of die tarychol esterol polyunsaturated fatty acids and saturated fattyacids.[26] The majority of b loodcho lesterd reducton demonstrated in the trials included in the meta-analysis could not be explained by substitution. Thus, substitution was not a confounder of the association between oat product consumption and blood cholesterol reduction.

One of the trials reviewed found that women over 50 years of age had a greater reduction in blood total cholesterol from oat consumption than younger women and younger and older men, even after contolling for the relatively higheri nitial cholesterol level of older women.[9] The hypothesis was tested in the meta- analysi but was notconfirmed.

Discussion

These findings can be considered from the perspective of both the public health specialist (i.e. population relevance) and from the clinician who treats hypercholesterolemic subjects.

It has been demonstrated, for countries with high average blood cholesterol, that a one percent reduction in the level of blood cholesterol of the population can effect a two percent reduction in mortality from coronary heart disease.[27,28] Thus, even modest reductions, when realized by large numbers of people, can have a very beneficial impact upon rates of heart disease.

Many of the trials reviewed for the meta-analysis enrolled normocholesterolemic subjects; the average initial cholesterol levels for the trials ranged from 4.6 to 7.2 mmol/L (179 to 278 mg/dL). Patients seen in clinical practice for hypercholesterolemia more closely resemble subjects included on the right side of Table 2 than the entire group of subjects analyzed for the meta-analysis. Thus, the benefit of an oat product intervention to patients seen in a clinical setting could be substantial, especially when benefit is defined in terms of efficacy, safety and cost-effectiveness; oats are an inexpensive, nutritious, non-pharmacologic intervention. It should be noted, however, that, although the meta-analysis was able to demonstrate a reduction in blood cholesterol with oat product consumption is additive to other diet modifications (i.e. low-fat, low cholesterol diet), the use of oats as a hypo-cholesterolemic agent should be viewed as only one component of a hearthealthy diet.

Table 2. Change in Blood Total Cholesterol Level With Oat Product Consumption By Dose of Soluble Fiber and Initial Cholesterol Level[1]

| | Initial Cholesterol Level | |
	<229 mg/dL	≥229 mg/dL
<3 grams soluble fiber from oats	-0.09 ± 0.10 mmol/L (-3.4 ± 3.8 mg/dL) (-2%)	-0.27 ± 0.04 mmol/L (-10.5 ± 1.6 mg/dL) (-4%)
≥3 grams soluble fiber from oats	-0.13 ± 0.12 mmol/L (-5.2 ± 4.8 mg/dL) (-3%)	-0.41 ± 0.21 mmol/L (-16.0 ± 8.3 mg/dL) (-6%)

1: Initial cholesterol level of 229 mg/dL was the median level of all the trials; 3 grams of soluble fiber was the median dose employed.

One of the practical difficulties of recommending an oat product intervention to appropriate patients is that the amount of soluble fiber is not routinely displayed on the ingredient panel of commercial products, and yet it is the item of interest to physicians recommending oats for its lipid-lowering ability. Commercial producers of oats could help engender both the clinicians' and the consumers' confidence in commercially available oat products by making this information readily available.

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Towards an Understanding of how Oats Lower Cholesterol

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Summary

ß-Glucan is the main fibre component involved in cholesterol reduction by oats and seems to act through alteration of intestinal lipid digestion and bile acid reabsorption. The consequent increase in steroid excretion is not due to a specific binding by oat components even though particular bile acids are excreted preferentially. ß-Glucan may also interact with oat oil in producing the overall effect in oats and oat bran. Effects of oat products on plasma lipids are not due to inhibition of hepatic cholesterol synthesis by propionate produced by colonic fibre fermentation. The lipid lowering by oats could be enhanced by other food components such as marine oils containing n-3 fatty acids.

Introduction

Elevated plasma cholesterol is generally accepted as one of the important risk factors in the early development of coronary heart disease (CHD) and cholesterol reduction is viewed an important step in CHD prevention. Dietary modification is an economic and effective means of attaining that end and of the dietary manoeuvres available, health authorities recommend reduction in total and saturated fat coupled with increased consumption of complex carbohydrates (starches) and fibre[4]. Effects of oats on plasma cholesterol have long attracted attention since the early observations of de Groot and colleagues[5] showing significant reduction of plasma cholesterol with rolled oats. Subsequent experimental work in both animals[e.g.10,23] and humans[e.g.14,33] has confirmed that oats and products such as oat bran can assist in lowering of plasma cholesterol. Much of the later work has been with the latter product, probably because of its higher content of dietary fibre.

A *meta*-analysis of the many studies of oats on plasma cholesterol reduction in human feeding trials will be discussed elsewhere in these *Proceedings*. Nevertheless, it is still relevant to affirm that inclusion of oats (products such as oat bran) in human diets does assist in lowering cholesterol. It has been debated whether the reduction seen in animals studies actually does occur in humans. The debate has arisen for two separate reasons. Firstly, early human studies showed very large reductions in cholesterol, of the order of 15-20%. More recent, carefully controlled studies have shown more modest (but very useful) reductions of total and low density lipoprotein (LDL) cholesterol of around 6%[14]. These reductions are of course, aside from any benefits of eating low-fat, high starch, fibre-containing oat products. Secondly, and much more importantly, a single report by Swain *et al.* [26] suggested that oat bran was ineffective. This study was a trial between two diets, both low in fat one of which contained oat products (as oat bran) while the other was based on low-fibre wheat flour. The study has a number of design problems which have been largely overlooked in favour of the conclusion that oats did not lower plasma cholesterol. As shall be seen later, this study may be compromised in another significant aspect which throws light on the mechanisms whereby oats and other cereals influence plasma cholesterol.

Oat Constituents that could affect Plasma Cholesterol

There are clearly two very important questions — what are the active components and how do they work? There are several candidates, two major (the oil and fibre) and a group of minor constituents (the tocopherols and tocotrienols). Of these, the former two have a fairly well-established candidacy while the latter seem to be losing ground.

Tocopherols and tocotrienols are lipid antioxidants and were first implicated in cholesterol reduction by Qureshi and colleagues[20] who showed that barley lowered plasma

cholesterol and contained an inhibitor of cholesterol synthesis. This was subsequently shown to be a tocotrienol which is present in other cereals including oats. However, further experiments have failed to show any relationship between the tocotrienol content of oats and their effects on plasma cholesterol in rats[11]. Oats contain significant quantities of an unsaturated oil which Judd and Truswell[13] concluded could contribute appreciably (possibly by as much as 50%) to the lowering of plasma cholesterol. This cannot be discounted as fats are known to be major influences on plasma cholesterol in both experimental animals and humans. Studies in rats have shown that delipidation of oat bran with solvent diminishes the effectiveness of oats in lowering cholesterol[13]. More importantly, relipidation did not restore the hypocholesterolaemic properties of delipidated oats suggesting either some close association between the oil and the non-lipid components was necessary or that the solvent treatment had disrupted some of those other constituents. The role of the fat may be a contributor to discrepancies in the magnitude of cholesterol reduction between more recent studies and the earlier experiments on oats. In the later work, the fat, fibre and other components have been carefully balanced to avoid differences in fat content or unsaturation index. The other major component that could affect plasma cholesterol is fibre. Oats are not the only plant foods to lower plasma cholesterol and a range of plant fibre preparations lower cholesterol in experimental animals and man and these preparations are characterised by their high content of water-soluble non-starch polysaccharides (NSP)[23]. Many of these NSP form highly viscous solutions in water and it is believed increased digesta viscosity mediates the cholesterol reduction and their other effects in the gut. In oats, one of the major NSP is a water soluble ß-glucan commonly referred to as oat gum which has high viscosity in solution[33]. Isolated ß-glucans also reduce cholesterol in animals[16] — supporting the claim that they are mediators of the effects of oats on plasma lipids.

Mechanisms for Cholesterol Reduction

Plasma cholesterol concentrations are regulated by two interlinked metabolic activities, i.e. entry and clearance. Clearance is effected by receptor and non-receptor mediated pathways and can be accelerated by increased loss of cholesterol from the body. This is the mechanism of action of cholestyramine, a well-known cholesterol-lowering anion-exchange resin which binds bile acids in the gut leading to enhanced faecal excretion with the deficit being made good by enhanced hepatic cholesterol catabolism and a lowering of plasma cholesterol[8]. The other mechanism for cholesterol lowering is by reduction of secretion into the plasma. This can be by inhibition of hepatic lipoprotein secretion or reduction of dietary cholesterol absorption.

It is accepted generally that there are only three ways in which food components can lower plasma cholesterol:
   a.   inhibition of synthesis;
   b.   enhanced steroid excretion; and,
   c.   altered absorption of dietary fat and cholesterol.

Of these, inhibition of synthesis has attracted much attention but now seems rather unlikely while the latter two have rather more support.

Inhibition of Synthesis

One potential group of inhibitors of hepatic cholesterol synthesis (the tocotrienols) have been mentioned already and seem not to be involved in the effects of oats on plasma cholesterol. A further inhibitor has been proposed by Anderson and colleagues i.e. one of the volatile fatty acids (propionate) formed by the colonic fermentation of NSP[2]. This is a very attractive hypothesis as propionate is a cheap and safe antifungal agent, used widely in the baking industry so addition of propionate to food is an established practice. The concept is based on several observations, largely in experimental animals. Firstly, foods such as oat bran which lower cholesterol are fermented by the colonic microflora of experimental animals with a greater production of propionate than occurs with foods such as wheat bran that do not lower cholesterol[11]. Secondly, propionate feeding lowers plasma cholesterol in experimental animals including rats and pigs[1,12] with reductions in

rats as great as those obtained with oat bran. Finally, propionate inhibits cholesterol synthesis in isolated hepatocytes[2], an effect similar to that of drugs used to lower plasma cholesterol in hypercholesterolaemic humans[27].

However, there are problems with the design of model experiments which seem to support a role for propionate. The time course of absorption of the acid formed by large bowel fermentation is quite different time course to that of propionate ingested by mouth and in pigs with portal venous cannulae, dietary propionate gave a peak concentration 1–2 hours after feeding followed by a decline[12]. After 4-6 hours, VFA concentrations rise and these raised levels are sustained for many hours, consistent with the onset and maintenance of large bowel fiber fermentation. In rats fed propionate-enriched diets, measurement of such a time course is impractical but determination of gut and portal venous VFA in the postabsorptive state shows that propionate concentrations are raised in the latter blood vessel. Propionate is raised also in the stomach but little appears in the small intestine (Table 1). In fact, in both rats and pigs most of the dietary propionate cannot be accounted for by portal transport which suggests metabolism by the stomach wall.

Table 1. Concentrations of propionate in gut contents of rats fed a diet supplemented with 5% sodium propionate.

Diet	stomach	duodenum (mmol/L)	ileum	caecum
Control	1	0	0	24
Propionate	116	1	1	24

Peak portal venous propionate concentrations after propionate feeding are in the region of 1 mmol/L, far lower than those used in hepatocytes. At these physiological concentrations no inhibition occurs in perfused liver[12]. Close examination of the data shows that large bowel propionate concentrations (which determine those in the portal vein) show no relationship to plasma cholesterol. In the pig, a similar lack of correlation has been found between plasma cholesterol and biliary steroids and portal venous propionate[30]. Although large bowel propionate is elevated when plasma cholesterol is reduced in experimental animals has been taken to mean a causative relationship between propionate and sterol homoeostasis, a recent experiment suggests the opposite may be true (R.J.Illman, G.B.Storer, and D.L.Topping, unpublished data). In that study with wheat milling fractions a strong negative correlation was found between caecal sterols (coprostanol and secondary bile acids) and plasma cholesterol in rats and a negative correlation was found between caecal propionate and plasma cholesterol. An even stronger positive correlation was found between caecal butyrate and cholesterol and as caecal secondary steroids increased, butyrate fell so propionate and butyrate may reflect large bowel steroid metabolism.

Enhanced Steroid Excretion and Altered Lipid Digestion

It seems convenient to address these two mechanisms together as they may be just different aspects of the same activity. Isolated water-soluble NSP (and the foods which contain them) which lower plasma cholesterol generally also increase bile acid excretion[27] and this is true for humans fed oats[13]. Greater steroid excretion has been shown in animals fed oat bran[6,10] and the increased bile acid excretion in these studies is similar to those seen with cholestyramine. The increased excretion is accompanied by greater biliary steroid secretion and increased hepatic cholesterol synthesis[10]. This increase in cholesterol synthesis has been observed also in humans with other water-soluble NSP (guar gum) which lower plasma cholesterol[18]. The analogy between oat bran and cholestyramine is heightened by the fact that there is increased excretion of particular bile acids which suggests some degree of specificity. Studies with model NSP and cholestyramine show that true adsorption of bile acids occurs with the ion-exchanger but not with NSP[31]. It appears rather more likely the enhancement in steroid excretion is secondary to a general expansion in the gut bile acid pool which, in turn reflects diminished

bile acid reabsorption. We presume that this is due to interference by ß-glucan through increased digesta viscosity. This would slow gut transit and the diffusion of bile acids into and out of digesta. This concept has some experimental support as isolated oat gum does interfere with nutrient digestion and absorption *in vitro* [17] and explains why isolated ß-glucans oppose dietary hypercholesterolaemia in rats[16].

A further conclusion from this mechanism is that the enhanced steroid excretion is only one consequence of an overall effect of viscous NSP on digestion. This is a very attractive concept as viscosity is thought to be an important factor in effects of water-soluble NSP in slowing carbohydrate absorption. There is fairly good evidence to support a role for viscosity in slowing digestion *in vivo* [28] and certainly water soluble NSP do modify the appearance of fats and cholesterol in the circulation[7,9]. This is also supported by the limited human data on viscosity which show that more viscous guar gum lowers cholesterol more than a less viscous one[25]. A note of caution need to be expressed as in animals, viscosity does not necessarily predict cholesterol reduction by purified NSP[30] which may be a consequence of using isolates instead of whole foods where several components may be cooperate with the NSP in producing the overall effect.

Mention has been made of an experiment with wheat milling fractions which may add further light on the mechanism of action of cereals. In that study rats were fed whole wheat, wheat bran and wheat pollard and also white wheat flour. Wheat bran is probably a suitable control for trials of cholesterol reduction with cereals as it is neutral with respect to plasma cholesterol or may be mildly hypercholesterolaemic[27]. Wheat fractions containing bran gave higher plasma cholesterol than the white wheat flour (Table 2). However, the latter fraction gave also significantly higher caecal concentrations of bile acids and neutral sterols — rather like oat bran[10]. Overall, there was a strong negative relationship between the latter and plasma cholesterol. A similar relationship also has been found with oat bran in baked products[6]. The latter finding is important as it confirms those of Kestin *et al* [14] with breads that effects of oats on plasma lipids survive this degree of processing. The effects of white flour raise the interesting possibility that in the trial by Swain *et al* [25] both diets were having similar effects on steroid metabolism.

Table 2. Plasma cholesterol and caecal steroids in rats fed whole wheat (WW), wheat bran (WB), wheat pollard (WP) and white flour (WF)

Diet	plasma cholesterol (mmol/L)	caecal sterols (mg/g)	caecal bile acids (mg/g)
WW	3.11	11.6	11.7
WB	2.97	17.2	22.1
WP	2.81	9.3	20.0
WF	2.57	29.0	48.9.

Oat Bran and Hepatic Cholesterol Synthesis — Interactions with Fish Oils

One interesting feature of the effects of oat bran on plasma lipids and hepatic lipid metabolism in experimental animals is that although steroid excretion may be increased very significantly (140+%), plasma cholesterol falls by only 20-25%[6,10]. This is almost certainly due to increased hepatic synthesis which prevents any further decline. Such a counter-regulation appears to occur in humans with other NSP[18] and may blunt the lipid lowering. Fish oils containing n-3 fatty acids lower plasma triacylglycerols very efficiently in humans[19] but do little to alter cholesterol[24]. Recently we have shown that in rats, feeding fish oils with oat bran potentiates the lipid lowering of the latter and inhibits the rise in hepatic cholesterol synthesis[21]. It should be noted that the effects of the n-3 fatty acids were in addition to any oil present in the oats. A combination of oats and n-3 fatty acids might be especially effective in lowering plasma lipids in humans and could give rise to processed foods with desirable nutritional properties.

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Oat ß-Glucans and Tocols

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Summary

The hypocholesterolemic effect of oat (*Avena sativa* L.) and oat products has been attributed to the soluble fiber fraction, ß-D-glucan. Feeding studies with chickens demonstrate that oat oil is also hypocholesterolemic due to its content of tocotrienols. The ß-glucan concentration of oat genotypes from the U.S. National Small Grains Collection is normally distributed with a range of 2.5 to 8.5%. Both ß-glucan and tocol concentration are affected by genotype and environment, with a small, but significant interaction. Oat products have similar concentrations of tocols as do oat groats, except for oat bran which is relatively higher in α-tocotrienol and lower in α-tocopherol, the two major tocols in oats. Some high-oil breeding lines have considerably higher tocol concentrations than do oats with normal oil levels. ß-Glucans accumulate late in grain development, whereas tocols accumulate early.

Introduction

Oat is known as a nutritious whole grain cereal, with a favorable quantity and quality of protein for human consumption. More recently, oat has been recognized for its high concentration of soluble fiber. Numerous studies demonstrating a cholesterol-lowering effect of oat bran or other oat products in laboratory animals and humans were summarized by Shinnick[21]. This effect of oat bran has been attributed to its high soluble fiber (ß-glucan) content, as demonstrated by rat feeding studies with an oat gum fraction[5,8]. When oat bran was separated into five fractions, only the gum fraction (60% ß-glucan) significantly lowered cholesterol of chicks[23]. The mechanism of the soluble fiber effect on serum cholesterol levels has not been resolved, but hypotheses involve increased viscosity of the intestinal contents slowing the rate of cholesterol absorption and the production of short chain fatty acids, known to inhibit cholesterol synthesis, by fermentation in the colon[3]. In addition to its cholesterol-lowering effect, oat soluble fiber lowers post-prandial glucose and insulin levels[4], making oat bran useful in treating type II diabetes[2].

Studies on adding cereal grains to chick diets[17] led to the identification of α-tocotrienol as a potent inhibitor of cholesterol synthesis[16]. This compound, high in oat and barley, may contribute to the cholesterol-lowering effects observed with oat bran.

In consideration of the potential value of soluble fiber and tocotrienols in oat, we initiated studies aimed at providing plant breeders with the information needed to breed new cultivars containing higher concentrations of these bioactive compounds. These studies include effects of genotype and environment, survey of available germplasm, and the effects of development. We have also looked at tocotrienol concentrations in a number of oat products and fractions.

Methods

Feeding studies

Two-week-old male chicks were fed a standard corn-soybean meal diet (control) for 4 weeks, after which they were killed and their blood and livers removed for analysis. Oat was substituted for part of the corn and soy to keep the diet isonitrogenous. Corn oil served as control for the oat oil treatments. Livers were homogenized and assayed for 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase activity as previously described[15].

Serum cholesterol concentrations were determined on precipitate and supernatant fractions[17] for analysis of low-density-lipoprotein (LDL) and high-density-lipoprotein (HDL) fractions.

Assays

$(1\rightarrow3,1\rightarrow4)$-ß-D-Glucan was assayed by enzymatic digestion and glucose assay[11] and by flow-injection analysis with Calcofluor[9]. Tocols were extracted with methanol, the solvent evaporated, dissolved in hexane, and assayed by HPLC on a silica column with fluorescence detection[14].

Results and Discussion

Feeding studies

Using the chick as a model, we discovered that feeding of certain cereal grains, especially barley and oat, in place of the standard corn-soy diet, lowered total and LDL-cholesterol and had no effect or elevated HDL-cholesterol. These changes are positive for reducing the risk of coronary heart disease. Incorporation at a 20% level in the diet achieved these changes without adversely affecting weight gain in the young birds. In addition, we noted that the rate-limiting enzyme for cholesterol synthesis, HMG-CoA reductase, was inhibited by the small-grain diets, indicating that the hypocholesterolemic effect cannot be attributed solely to a fiber-enhanced excretion of cholesterol metabolites. This led us to extract and test the oil fractions from several sources, and oil from oat, barley, palm, wheat germ and others, when incorporated into the diet at 10% levels, had similar effects to the whole grains as compared to 10% corn oil. We further determined that the active fraction was methanol-soluble. These results for oats are shown in Table 1. Subsequent tests using primarily barley or palm oil indicated that the tocotrienols were the active component in the oil. These compounds, which exist as a series of isomers differing in the number and position of methyl groups on the chroman ring, are counterparts of tocopherols, except the tocotrienols have three double bonds in the phytyl tail[12]. We have subsequently shown, using tocotrienols from sources other than oat, that γ- and α-tocotrienol are the most potent isomers, although α-tocotrienol is also effective[19,22]. Using a concentrated fraction of tocotrienols from palm oil, 200 mg daily significantly lowered total and LDL-cholesterol in hypercholesterolemic human subjects[19]. In consideration of these results and previous studies, we have investigated both ß-glucan and tocotrienols in oat.

ß-Glucan

A major objective of our research is to screen the oat entries in the U.S. National Small Grains Collection, stored at the National Small Grains Germplasm Research Facility at Aberdeen, Idaho. This screening will identify germplasm useful to plant breeders attempting to develop high ß-glucan oat cultivars as a specialty crop for human food. Prior to initiating this screening, we needed to determine the effects of environment, genotype and their interaction on ß-glucan levels. We selected 12 cultivars, and had them grown at experiment stations in nine locations throughout the U.S. in replicated plots. The seed was returned to our laboratory for analysis. We found significant differences for cultivars and for location, and the interaction was also significant[13]. However, the interaction variance ratio was small relative to those for the main effects. Furthermore, rank correlations between locations were positive and generally significant, indicating that cultivars performed similarly in the different locations. We concluded that samples from the National Small Grains Collection, all of which were grown at Aberdeen, would be representative of the performance of these genotypes at other locations.

We are presently in the midst of screening the more than 21,000 oat entries in the National Small Grains Collection for ß-glucan, protein and oil. Results for the first 2,878 entries analyzed reveal a range in ß-glucan concentration of 2.56 to 8.45% (mean=5.05, CV=14%). The values appear to be normally distributed. A list of the ten highest and ten lowest entries is shown in Table 2. So far we have not discovered any extreme outliers, such as have been found for certain waxy barleys. There is no correlation between ß-glucan and protein among these samples, indicating that selection for both characters could be made

simultaneously. This contrasts with a recent report that ß-glucan and protein were significantly negatively correlated among five oat varieties in Finland[20].

Table 1. Effects of dietary oats, oat oil, and methanol-soluble fraction of oat oil on weight gain, serum cholesterol, and hepatic HMG-CoA reductase activity in 6-week-old chicks.[a]

| Dietary substitution | Weight gain | Serum cholesterol | | | HMG-CoA reductase |
| | | Total | HDL | LDL | |
	(------------- % of control[b] -------------)				
20% Oat[c]	109	91	111	76	66
10% Oat oil[d]	98	87	103	81	68
Methanol-soluble fraction[d,e]	103	73	85	69	60

[a] Fed ad libitum for 4 weeks. Ten chicks per group.
[b] Standard corn-soybean meal diet. All diets isonitrogenous.
[c] Qureshi et al. [18]
[d] Unpublished data of A.A. Qureshi et al.
[e] Equivalent to 10% oat oil.

A study to measure the ß-glucan content of elite oat germplasm, and assess its relationship, if any, to agronomic characteristics, was carried out in cooperation with Dr. Darrell Wesenberg. Samples of the Uniform Early Oat Nursery (UEON) and the Uniform Midseason Oat Nursery (UMON), grown under irrigation at Aberdeen, Idaho in 1988-1991, were analyzed for ß-glucan and protein. For both nurseries, there were highly significant differences in groat ß-glucan concentration among lines each year. The highest lines had ß-glucan concentrations of 6.3 to 6.6% (UEON) and 6.1 to 7.0% (UMON), whereas the lowest had only 4.3 to 4.7% (UEON) and 3.1 to 4.6% (UMON). These results indicate a narrower range of values for the elite germplasm than for the national collection. Nevertheless, there is about a 50% increase from low to high in the elite nursery germplasm, indicating significant variation for this character in well adapted lines.

Table 2. Oat samples from the National Small Grains Collection with the lowest and highest ß-glucan concentrations.

PI number	% ß-glucan	PI number	% ß-glucan
Lowest:		Highest:	
PI 497769	2.56	PI 504601	7.03
PI 287313	2.70	PI 412928	7.16
PI 401772	2.73	PI 361886	7.20
PI 374397	2.82	PI 193957	7.24
PI 326221	2.96	PI 504611	7.30
PI 386169	3.00	PI 361884	7.32
PI 401790	3.04	PI 504593	7.33
PI 401771	3.13	PI 502955	7.75
PI 258644	3.22	PI 194895	8.41
PI 287300	3.23	PI 258616	8.45

Samples from the 23 lines in the 1991 Cooperative Naked Oat Test from seven locations were analyzed for ß-glucan. There were significant differences among lines and locations. The lines, averaged across locations, ranged from 4.7 to 3.9% ß-glucan. Although covered check varieties from these nurseries were not available for analysis, the results suggest that naked oat has lower levels of ß-glucan than groats from covered oat, and that the naked oat elite germplasm has less variability for this character.

A long-range objective of our research is to discover the mechanism of synthesis of the ß-glucan and determine how ß-glucan synthesis is regulated during grain development. As a first step, we have measured the accumulation of ß-glucan in developing caryopses of oat (cv. Dal) from plants grown in an environmental chamber. ß-Glucan accumulation occurred predominantly after the rate of dry weight increase had peaked (Figure 1). A similar result was reported by Åman et al. [1]. Since the ß-glucan occurs in the cell walls of the starchy endosperm[7], it appears that the relatively late increased amount coincides with the thickening of the subaleurone layer cell walls.

Tocotrienols

Groats from 12 cultivars grown at three locations in the U.S. (North Dakota, Indiana, and New York) were extracted and analyzed for tocol content to determine effects of genotype, location and their interaction. Total tocol concentration ranged from 19 to 30 mg kg^{-1}[14]. α-Tocotrienol and α-tocopherol were the predominant isomers, with lesser amounts of γ-tocopherol, ß- and δ-tocotrienol. There were highly significant differences among genotypes and locations for total tocols and most of the isomers. Although the genotype X location interaction was also significant, most of the variance was associated with the main effects, and correlation coefficients between locations were generally positive and significant. We concluded that the relative rankings of genotypes among environments was relatively stable, indicating that breeding progress for higher tocols is feasible.
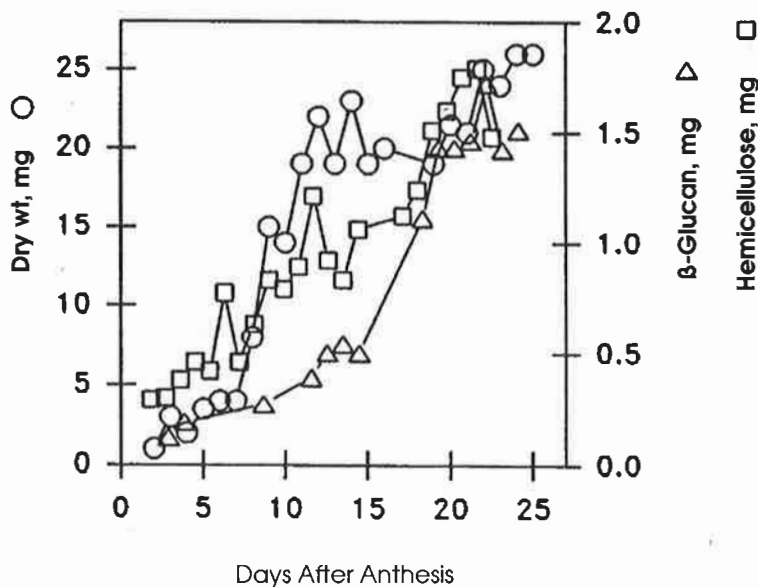
Figure 1.   Dry weight, ß-glucan and hemicellulose increase with maturation in Dal oat (per grain basis)
(J. L. Koch and D. M. Peterson, unpublished data).

A number of high-oil oat breeding lines were obtained from Dr. K.J. Frey of Iowa State University to test the hypothesis that the tocol content may be related to oil content. Ten lines with a mean oil content of 13.7 ± 0.3% were compared to three check cultivars of 5.1 ± 0.5% oil. The high-oil lines averaged 54 ± 5 mg kg^{-1} total tocols versus 26 ± 3 mg kg^{-1} for the checks, a 2-fold increase. The distribution of tocol isomers was altered, the high-oil lines having a lesser proportion of tocopherols.

Several milling fractions and products were obtained from The Quaker Oats Company and analyzed for tocol content. Generally, dried groats, oat flour, and various rolled oat products had similar tocol content and distribution as did green groats. The exception was oat bran, which was 36% higher in α-tocotrienol and 27% lower in α-tocopherol. This enrichment in α-tocotrienol, along with higher ß-glucan in oat bran, is potentially beneficial for healthful diets. However, preliminary observations indicate that the tocols may degrade upon storage of the processed products at room temperature. This preliminary observation needs further study.

The concentration of tocols during development was examined in two cultivars that were field-grown in Aberdeen, Idaho. The major increase in tocol concentration occurred between 7 and 14 days after heading, with slight increases thereafter (Figure 2). On a per seed basis, tocol content increased until 21 days after heading. α-Tocopherol and α-tocotrienol increased as a percent of total tocols, and the other isomers decreased with kernel development.
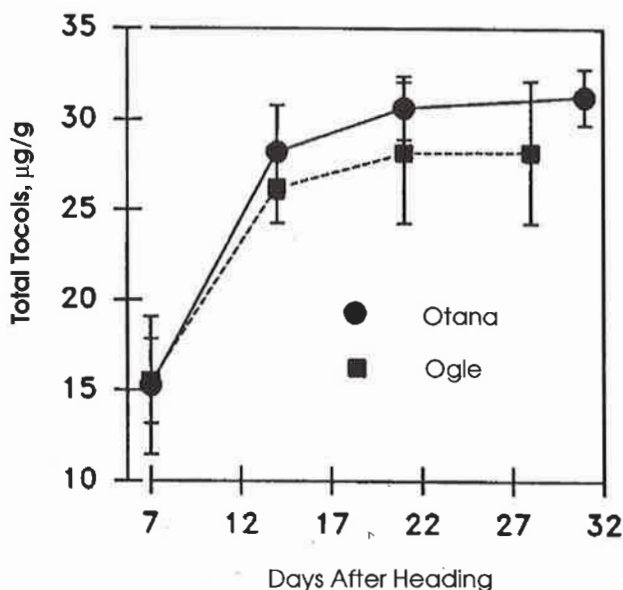
Figure 2. Total tocol concentration in oat grain during maturation in the field (D. M. Peterson, unpublished data).

Conclusions

These studies indicate that there is significant variation among oat germplasm for the bioactive constituents, ß-glucan and tocols, that could be used by breeders to develop adapted cultivars containing elevated levels of these value-added traits. High ß-glucan cultivars, in conjunction with processing methods to concentrate the ß-glucan[10], should enable oat millers to produce useful products containing sufficient quantities of the soluble fiber to affect cholesterol metabolism without the necessity of consuming unusually large quantities. For tocols, concentrations in unfractionated oat are probably insufficient to have a cholesterol-lowering effect for humans, although tocols are beneficial as anitoxidants at much lower concentrations. However, should oat be developed as an oil crop as has been proposed[6], the extracted oil (400-500 mg kg^{-1} tocols) would be suitable for further processing to concentrate the tocols.

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Starch Characteristics of Australian Oat Cultivars

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> *"Oats: a grain which in England is fed to horses, and in Scotland forms the mainstay of the people."*
> **Dr Samuel Johnson,** A Dictionary of the English Tongue, 1755.

> *"True Sir: and where else can one find such horses? Or such men?"*
> **James Boswell,** Johnson's long-suffering (Scottish) biographer.

Summary

The viscographic characteristics of the starches of Australian oat cultivars were examined with a Rapid Viscoanalyser. Firstly, the viscographic characteristics of an oat sample with unacceptable quality were determined and a possible cause of the problem identified. Secondly, a survey of oats grown across NSW in three seasons was carried out. This indicated that varietal differences were less important than growing conditions in determining viscographic characteristics of oats.

Introduction

The starch of oats has been of little interest to cereal chemists, not *per se*, but because, in contrast to most other cereals, it cannot easily be separated from the other components of the grain. Thus there is no starch industry using oats as feedstock analogous to those based on maize, as in the USA, or wheat, as in Australia.

Paton[5] commented that .... *"no single commercial use of an oat component provides the necessary driving force for utilisation of oat fractions."* This has further reduced interest in the industrial applications of oat starch, with most suggestions being confined to highly specific and small-scale uses such as wallpaper adhesives. As a consequence, relatively few references are found in cereal chemistry literature on the functionality of oat starch.

Morphologically, oat starch differs from that of other cereals. The granules are only weakly birefringent, irregular in shape (often polyhedral), tend to exist in clusters, do not fall into discrete size distributions (i.e. A and B granules), and are not embedded in a continuous protein matrix, as the protein is localised in discrete structures.

In pasting behaviour, oat starch was characterised by MacMasters *et al.* [3] as very similar to that of maize. This was the generally accepted view until Paton[4], using the Ottawa Starch Viscometer rather than the Brabender Amylograph, showed distinct differences from other cereals in the pasting of oat starches. Under greater shearing power and more rapid temperature changes, oat starch was shown to have greater susceptibility to shear forces and greater increase in viscosity on cooling. Both these factors have relevance to the processers of oats for human-food use, as retention time in a typical vertical-column groat steamer is about 12-15 min[5], whereas the Amylograph takes over 40 minutes to raise the temperature to 95°.

Almost all the published studies on oat starch have been on isolated starch fractions, which required a difficult and time-consuming procedure even when employed on a laboratory scale. For a chemist working with plant breeders, selection based on difficultly-isolated starch is not practical. Therefore, when the Agricultural Research Institute obtained a Rapid

Viscoanalyser (RVA), all investigations of its capabilities were carried out with ground "green" groats: no attempts were made to isolate the starch component. The RVA is similar in operation to the Ottawa Starch Viscometer, being capable of both rapid mixing and rapid changes in sample temperature.

Methods

Samples were ground with a cyclone grinder fitted with a 1 mm screen. The tests were carried out using a Newport Scientific Rapid Viscoanalyser, with a grist/liquid ratio of 4g/24mL and a stirring speed of 160 rpm. The temperature controller raised the temperature from 60° to 90° at 12°/min, held for 5 min, dropped to 60° at 7.5 deg/min and held for 3 min.

Results and Discussion

The "typical" Rapid Viscogram of "green" groats and the temperature profile used are shown in Figure 1. Viscograms of "green" groats were characterised by a relatively small initial peak due to gelatinisation (the Peak Viscosity, PV), a small drop in viscosity due to mechanical damage (the Trough, T), followed by a substantial increase in viscosity on cooling. It is this latter increase, referred to as the "Setback", which characterises both the amylograms[2] and the viscograms of oats.
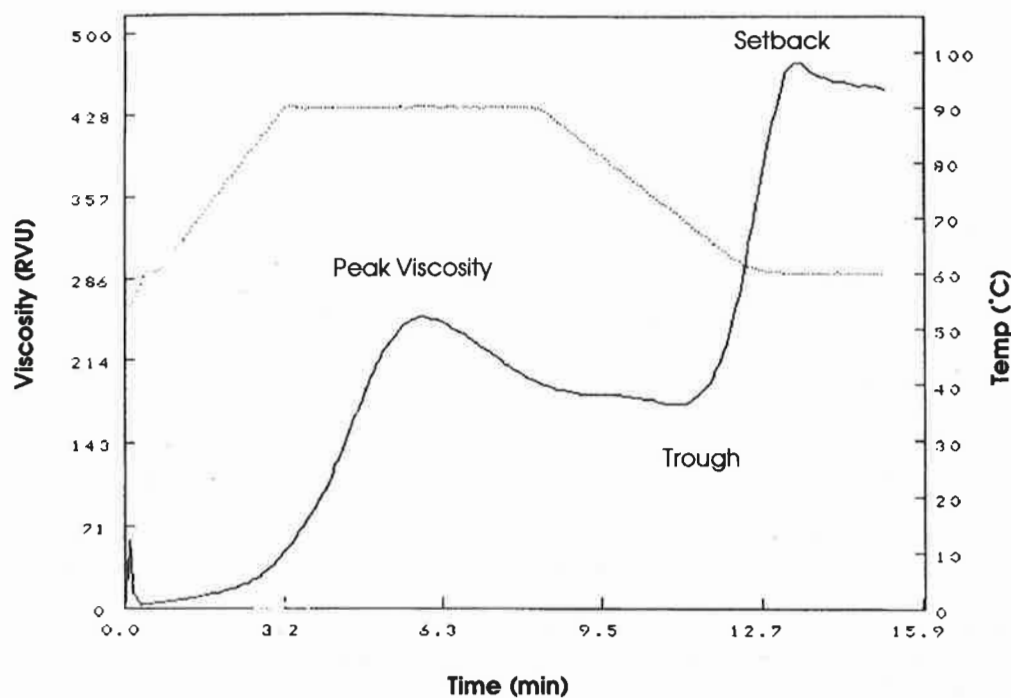
Figure 1.   Viscogram of Typical "green" Groats

Viscographic characteristics of a problem sample

Recently, rolled oats made from the variety *Yarran* were found to be unacceptable to consumers, although none of the standard Quality Control tests identified the problem.

Figure 2 shows the rapid viscograms of the dried groats. Firstly, it was noted that the Setback had been substantially reduced, and the Shear Susceptibility increased, compared to the "green" groats, presumably by preprocessing in the factory. The Peak Viscosity (PV) and Setback of the Yarran were lower than those of the other cultivars Mortlock and Cooba, despite having the lowest protein content (Table 1). The Yarran also showed a significant delay in the Time-to-Peak Viscosity (TTPV). The cultivars differed little in Shear Susceptibility (PV + T). The rolled oats gave viscograms similar to those of the groats.
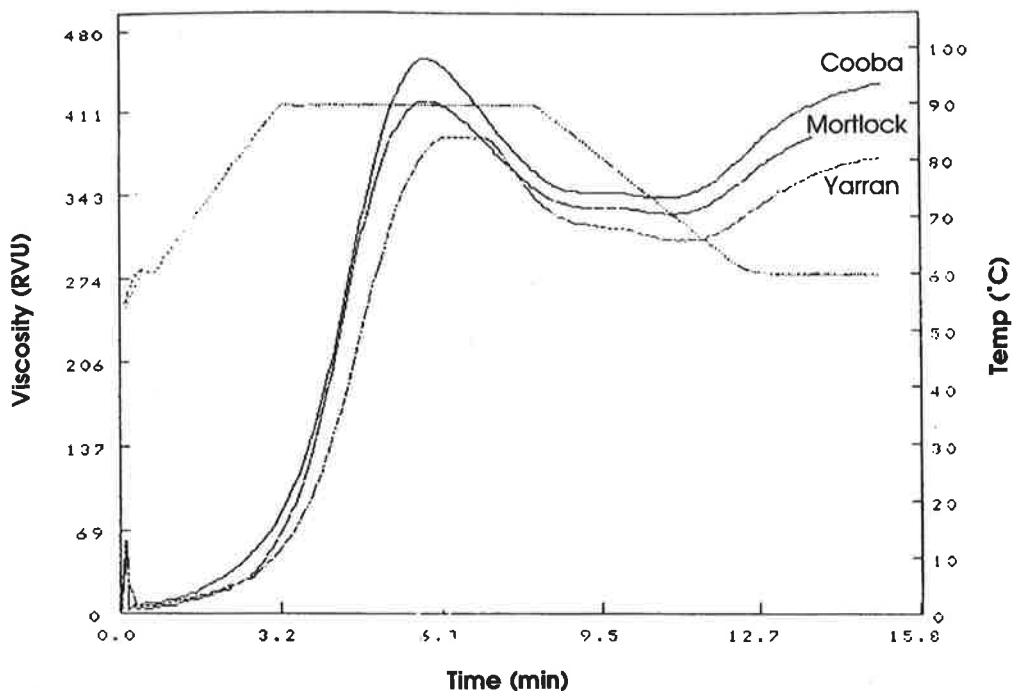
Figure 2.   Viscograms of Dried Groats

Table 1.   Analytical data for three samples of kiln-dried hulled oats.

Variety	Protein	Moisture	Oil
Cooba	11.2	11.1	7.0
Mortlock	9.4	12.7	8.0
Yarran	8.7	10. 2	10.2

Yarran had a substantially higher oil content than the other cultivars (Table 1). It was suggested from the work of Goering *et al.* [1] that a amylose:lipid interaction was responsible for the delayed TTPV and lower Setback. The ground groats were extracted with petroleum ether for 16 hours, and portions of defatted and untreated meals were mixed to give a range of oil contents. These were tested on the RVA, with the sample weights corrected for the changes in oil content. The TTPV of all three cultivars was further delayed as oil was removed, with the TTPV of Yarran remaining the longest at all oil contents (Figure 3(a)).

Setback remained lower in the samples of Yarran than the other cultivars. As shown in Figures 3(b) and 3(c), changes in Peak Area and Setback decreased with decreasing oil content to a minimum and then increased. Peak Viscosity (Figure 3(d)) followed this pattern in Mortlock and Cooba, whereas in Yarran the PV increased with decreasing oil content. Changes in Shear Susceptibility were inconsistent with changes in oil content.

These results suggested that the critical viscogram parameters were Peak Viscosity, Time-to-Peak Viscosity and Setback. It is proposed that cultivars with longer Times-to-Peak Viscosity receive insufficient treatment during steaming, prior to cutting and rolling, to produce an acceptable product.

Thus the Peak Viscosity, the TTPV and the Setback values of oats could possibly be used by processers as selection criteria for purchasing, but to be useful to the breeder's chemist for crossbred selection, viscogram characteristics must be cultivar-, rather than environment-dependent. Published studies on the pasting behaviour of oat starch have been confined to very few cultivars, with no consideration of the effects of environment or environment x genotype interactions.

Time-to-Peak (min)

Oil Content (%)

— Cooba   —+— Mortlock   —*— Yarran
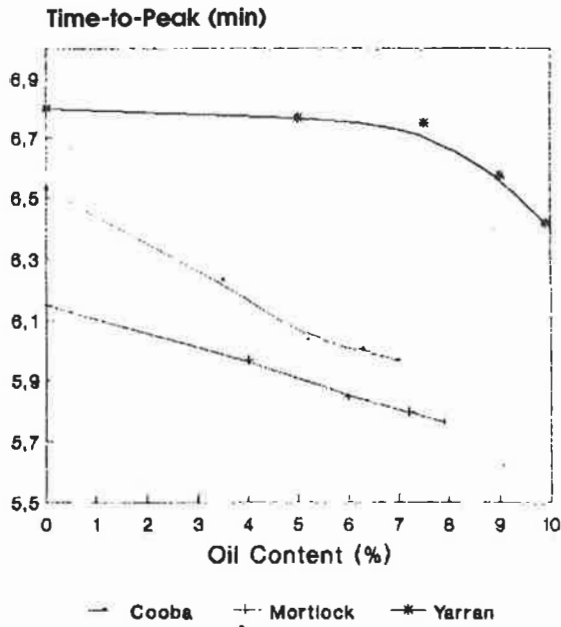
Figure 3(a). Change in Time-to-Peak
with change in oil content

Peak Area (RVU/min)

Oil Content (%)

—•— Cooba   —+— Mortlock   —*— Yarran
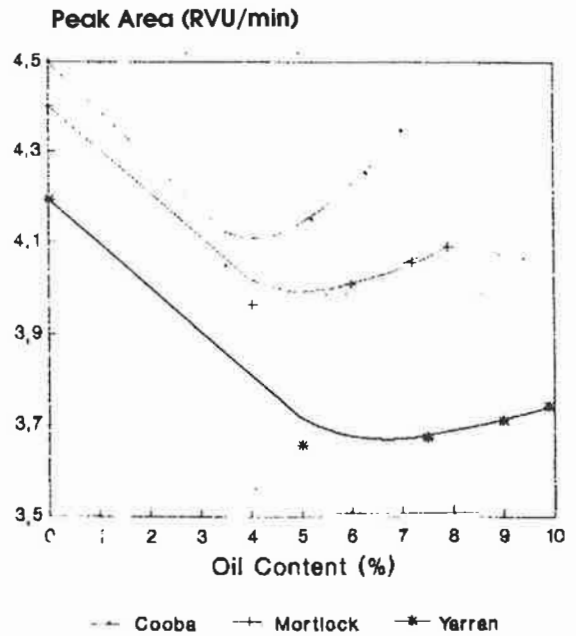
Figure 3(b). Change in Peak Area
with change in oli content

Peak Viscosity (RVU)

Oil Content (%)

—•— Cooba   —+— Mortlock   —*— Yarran
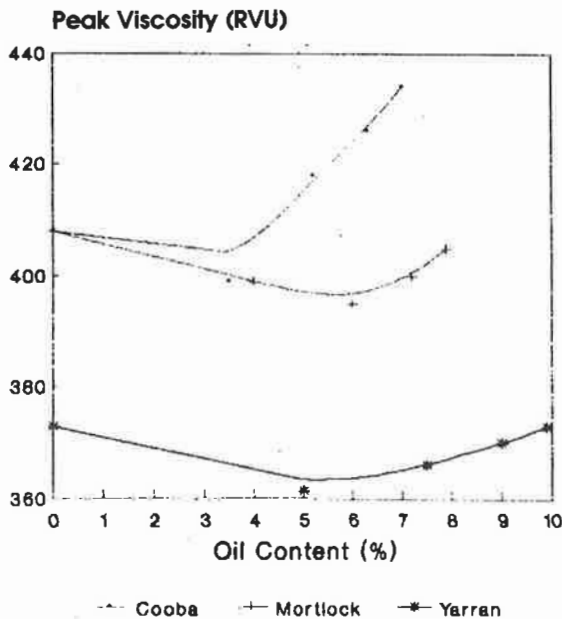
Figure 3(c). Change in Setback
with change in oil content

Peak Viscosity (RVU)

Oil Content (%)

—•— Cooba   —+— Mortlock   —*— Yarran
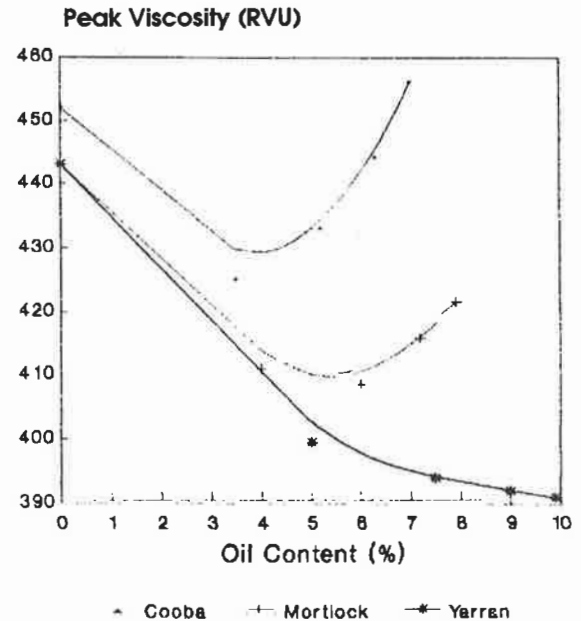
Figure 3(b). Change in Peak Viscosity
with change in oli content

Survey of NSW-grown oats

To investigate the range in viscogram characters in oats grown in NSW, samples of six
named cultivars and three advanced crossbreds from twelve trials grown across NSW in
1990 were then tested on the RVA. Not all cultivars were present in each trial. The testing
protocol was as given above.

Cultivars did not display characteristic viscograms, due to substantial variations caused by
growing area and climatic conditions. No differences in Peak Viscosity, Time-to-Peak
Viscosity, Shear Susceptibility or Setback were statistically significant. The means and
standard deviations of the results are shown in Table 2.

Table 2. Means and standard deviations of viscogram data from samples of the 1989 harvest.

Cultivar		Time-To-Peak Viscosity	Susceptibility (Peak/Trough Viscosity)	Peak Viscosity	Setback
Yarran	n=7	7.1 ± 1.9	1.17 ± 0.06	363 ± 40	634 ± 60
Mortlock	n=8	6.0 ± 0.4	1.19 ± 0.14	401 ± 60	711 ± 86
Echidna	n=7	6.8 ± 1.4	1.15 ± 0.05	379 ± 35	660 ± 69
Cooba	n=9	6.1 ± 0.3	1.24 ± 0.12	405 ± 47	691 ± 35
Coolabah	n=7	6.7 ± 1.3	1.17 ± 0.08	403 ± 38	703 ± 39
Dalyup	n=5	6.9 ± 1.6	1.21 ± 0.09	402 ± 50	666 ± 65
MA5027	n=6	6.5 ± 0.4	1.19 ± 0.10	401 ± 39	677 ± 27
MA5028	n=7	6.2 ± 0.3	1.20 ± 0.09	428 ± 33	739 ± 25
Bandicoot	n=5	7.9 ± 1.9	1.19 ± 0.05	416 ± 29	667 ± 58

There was a high correlation between oil content and both TTPV and Setback, but only within cultivars (Table 3). Protein would be expected to be strongly negatively correlated with viscogram characteristics, even if only acting as a diluent for starch, but the correlations were less than those for oil.

Table 3. Regression correlation coefficients ("r") between oil or protein contents and viscogram characteristics for samples from the 1989 harvest.

	Setback		TTPV	
Cultivar	Oil	Protein	Oil	Protein
Cooba	-0.71	-0.32	-0.63	-0.34
Mortlock	-0.66	-0.41	-0.79	-0.46
Yarran	-0.85	-0.48	-0.89	-0.51
All Cultivars	-0.30	-0.28	-0.19	-0.27

The variations due to growing area were as evident in the data from the 1988 and 1990 harvests and thus the RVA would appear to offer little information for screening crossbreds, particularly in early generations. Table 4 shows that the variability between the cultivars in an individual trial was comparable to that between cultivars across trials. The Yarran did not display the long TTPV shown by the commercial sample discussed above, but the Yarran sample from the late-sown trial at the same site did (TTPV 9 min). It was then noted that, in almost all cases, samples with long TTPV values were from late-sown trials. Figures 4 & 5 show the three cultivars, Cooba, Mortlock and Yarran, from an early and late sown trial at the same site. The general shape of the viscograms appear to result from sowing time as much as from cultivar. Maturation of the grain from the late-sown trial would have occurred under hotter and drier weather than those of the early-sown trial: Yarran appeared to be most affected by sowing date. This relationship is worthy of further investigation.
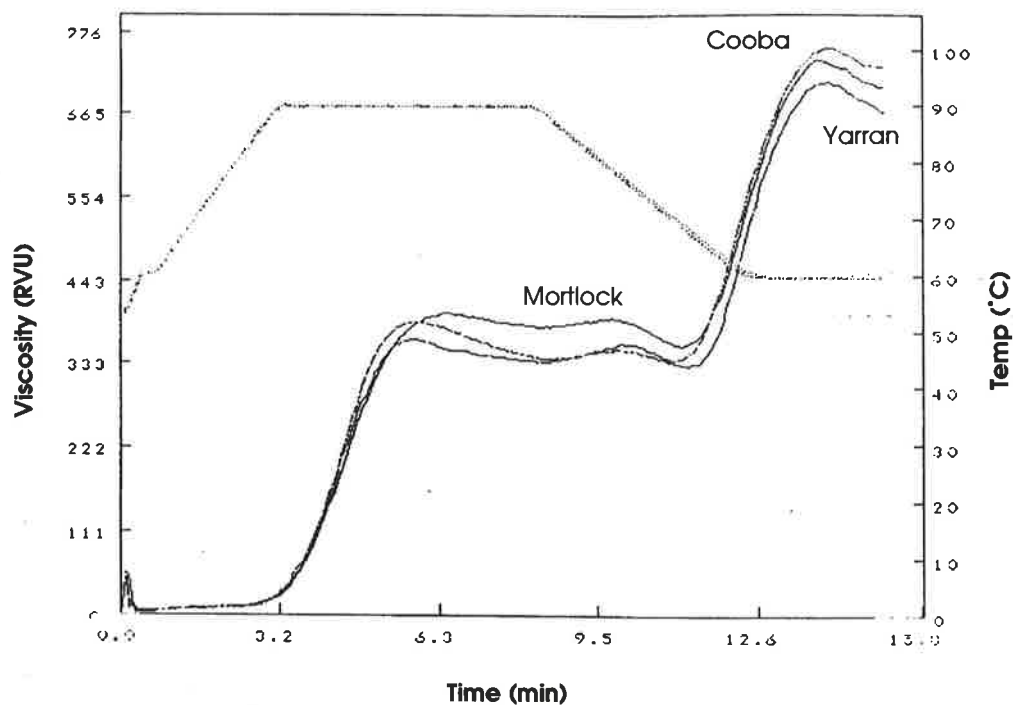
Figure 4.   Early Sown Trial: Condoblin 1989
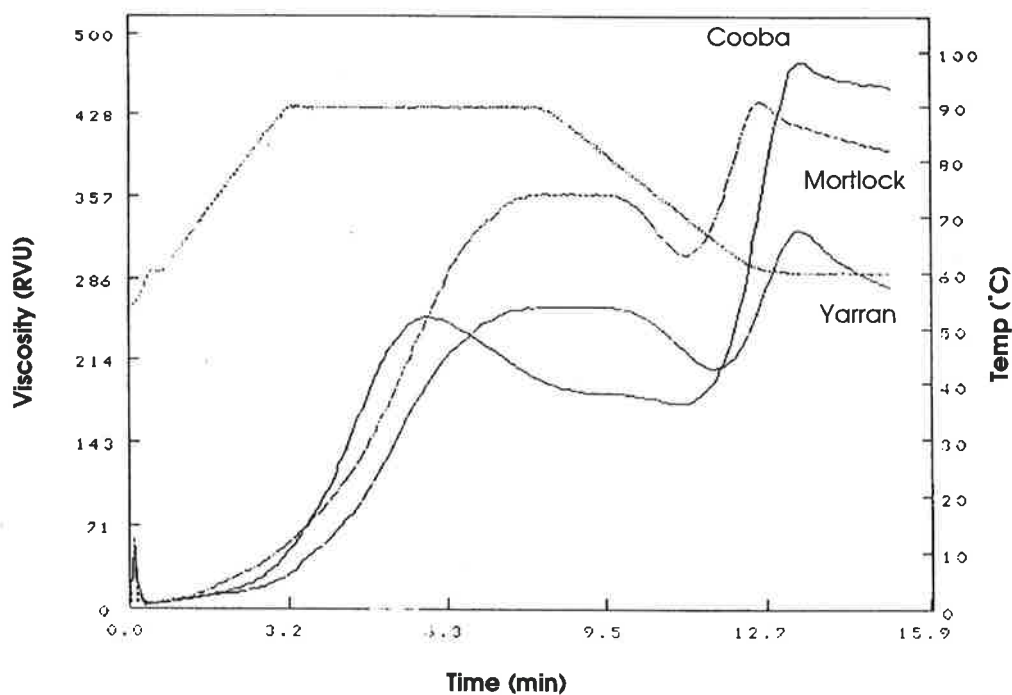
Figure 5.   Late Sown Trial: Condoblin 1989

Table 4. Viscogram data from samples of Condobolin early-sown trial of the 1989 harvest.

Cultivar	Time-To-Peak Viscosity	Susceptibility (Peak/Trough Viscosity)	Peak Viscosity	Setback
Yarran	5.82	1.12	367	709
Mortlock	6.42	1.12	401	738
Echidna	5.70	1.11	378	761
Cooba	5.83	1.16	389	755
Coolabah	9.62	1.16	414	699
Dalyup	5.70	1.30	484	762
MA5027	7.02	1.13	398	689
MA5028	6.75	1.14	417	745
MEAN SD	6.61 ± 1.3	1.15 ± 0.1	393 ± 55	732 ± 29

Conclusions

The starch characteristics of oats, as measured by the Rapid Viscoanalyser, are strongly influenced by environment, oil and protein content. The variability within cultivars due to environment was such that selection of crossbreds in a breeding programme would be difficult. The RVA can provide information on starch functionality suitable for processers to make informed decisions on the suitability of deliveries of oats for human food-use purposes. However, the effective use of this instrument would require the development of a substantial database from which appropriate parameters could be defined. This database is also necessary for effective selection of crossbreds from a breeding programme.

Further investigation into the pasting characteristics of Australian cultivars of oats is made more difficult by the lack of small-scale apparatus for testing cultivars for human food use. Unfortunately, as shown by the quotation which heads this paper, the proportion of oats directly entering the human food chain is insufficient to justify the development or purchase of such equipment for use in Australian oat breeding programmes.

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Oat Grain Quality Effects on Oat Milling Efficiency

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Abstract

Oat grain quality can be defined in many ways, such as: test weight or bushel weight, chemical component percentages (especially protein, fat and fiber), physical structure, contamination and percent groat/hull. Oat milling companies use these parameters as raw material quality indicators, but use mill yield (amount of raw grain producing a standard amount of product) to indicate oat milling efficiency. Samples of oats with a known mill yield were collected at a major oat milling plant at Cedar Rapids, IA, USA. These samples were analyzed for test wt, groat percent, 1000 kernel wt, kernel area, F-shape, length, width, density, and volume. Other parameters were derived using the above physical measurements. All physical measurements were done by digital image analysis. Statistical analysis was used to correlate the physical characteristics to mill yield. Although test weight has been used in the past as an quality indicator, a correlation between test weight and mill yield had an unsignificant R^2 of 0.147, whereas the correlation between percent groat and mill yield had a significant (>0.001%) R^2 of 0.534. Correlation of the other measured physical traits were not significant, however, there was significant correlations between the variability of the morphological traits and mill yield. Results will be presented comparing these parameters and their impact on oat milling efficiency.

Advances in Technology for Oat Milling

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Summary

Today's objects of oat processing mentioned before may show by example that on-going continuing development of appropriate machines and technologies greatly contributes to increasing efficiency in oat processing. This in particular relates to higher yields obtained in hulling, an economy of energy as well as convenience in operation and maintenance.

The example OAT BRAN serves to explain that an appropriate selection and combination of machines is a major prerequisite for the production of oat foods with specific characteristics.

These examples further demonstrate that the object of producing oat-based foods which satisfy consumers' demands these days as to appearance, taste, nutritional value and biological valence can be achieved only by combining cultivators, growers, machine suppliers and producers in their activities.

Introduction

Today's object of processing oats is to give a great number of oat foods an outstanding taste and nutritional value. Marketable oat foods can be produced as a function of top quality raw material delivered to the oat mills whereas the appropriate machines and technologies to the latest findings are another major prerequisite.

The requirements of the raw material oats relate to:

- the outer character of groats, such as size and appearance of groats;
- groats with its constituents such as protein, fat, dietary fiber, Beta-Glucan and their composition;
- characteristic attributes in milling, i.e. content of glumes and susceptibility to breakage.

Today's demands on oat processing machines are placed on:

- their optimized design, closely matching the particular application;
- economy of energy
- easy-to-operate, ease of maintenance
- possibility of integrating process automation.

The entire processing sequence should be set up as clearly and logically as possible, thereby maintaining the plant at optimum running conditions.

Worldwide increasing demands for oat foods during the past 10 years more and more call for an appreciable extension of oat mill capacities. Expanding demands have meanwhile reached a high and stable standard. Thus, contemplation these days does no longer reflect upon an extension of production capacities but tends rather towards rationalisation measures in production, thereby increasingly directing towards the production of customized products.

By means of some examples hereafter I will explain the importance of on-going development of state-of-the-art machines and technologies.

Optimizing the Hulling Process

Up to now it was not possible to change the state of naked oats so as to allow any appreciable quantities of oat foods to be produced therefrom for human consumption. In the order of individual processing stages in oat mills, oats is first guided to undergo hulling.

The hulling job is performed in three stages: hulling of oats, separation of glumes by air sifters whereas table separators are used to sort unhulled groats from the hulled ones. When discharged from the table separators, the unhulled oats is returned to the hullers[1].

Impact hullers are nearly throughout applied these days to the actual hulling process. When fed towards the impeller which circulates at a defined speed inside the impact huller, the oats is subjected to acceleration and an intensive impacting process, thereby detaching the glumes from the groats.

This hulling process was extensively and thoroughly tested by us, using state-of-the-art techniques, high-speed film cameras, etc. Always intent on the refinement of process technology, the experience acquired in this way is reflected in a new huller design. This greatly contributes to increasing hulling efficiency which at the same time reduces breakage as compared to the previous huller type.
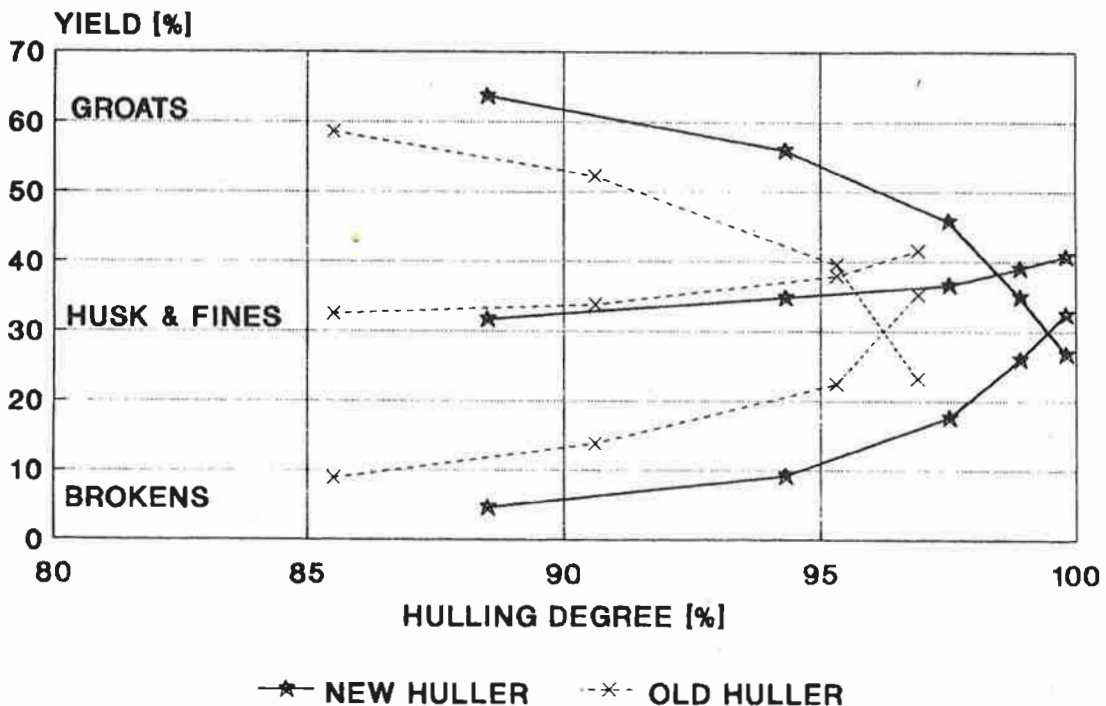
Figure 1.   **Hulling of Australian Oats** — Husk Content 28.5%; Moisture 11.1%

Figure 1 shows the outcome of comparative tests run on the two huller types as a function of hulling efficiency in view of groats, breakage and glumes with light material obtained in hulling of Australian oats. This clearly shows the increased hulling efficiency performed.

Groats breakage obtained in hulling is a mix of big and small brokens down to fine grits. Due to their floating velocity which equals that of the glumes, small brokens are carried off by means of sifting air during subsequent separation of glumes. Small brokens are thus past recovery.

The yield of groats will increase as the percentage of breakage obtained in hulling is totally reduced. This will in particular prove advantageous in the production of products with a high proportional content of whole-groats.

According to statements made in previous issues[2], the characteristic behaviour of oat lots proves divergent in hulling as to yield and susceptibility to breakage as a function of variety, origin and state. Figure 2 shows the outcome of hulling oats from different cultivation areas on either huller type, particularly in view of their divergent characteristic attributes in hulling.
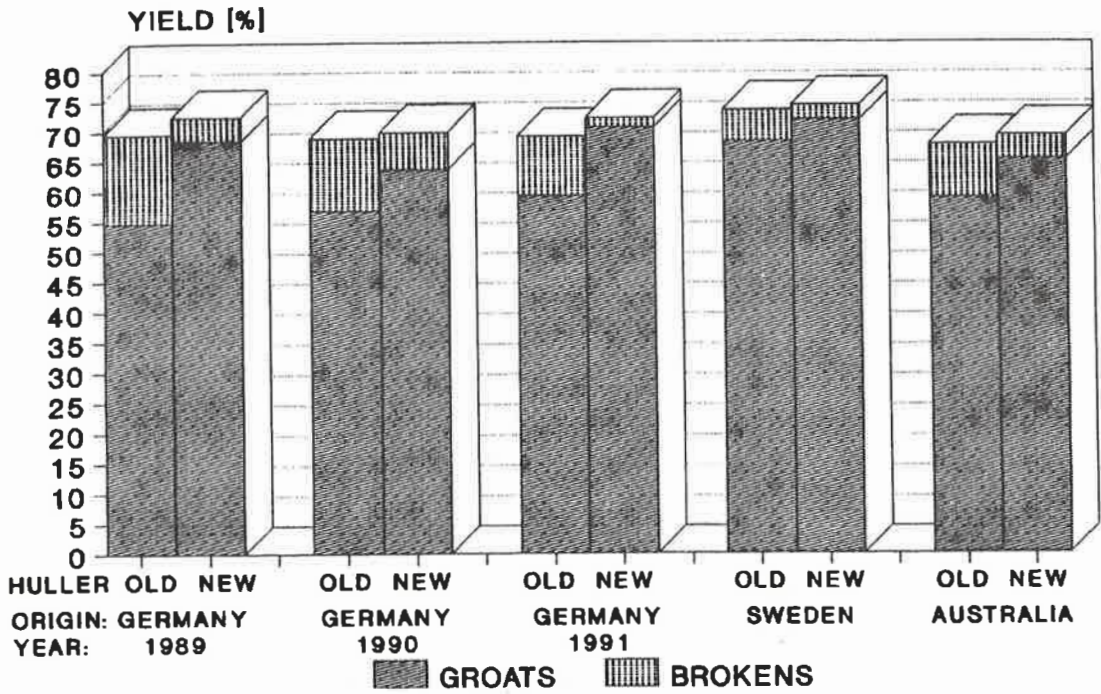
YIELD [%]

Figure 2.   **Hulling of Oats of Different Origin** — Hulling Degree 85%

Reducing the Energy Demand

This optimized huller design is instrumental in obtaining higher yields of groats, thereby greatly contributing to operating economics.

Air recycling sifters, when applied to aspirate the glumes, operate just the same for reducing the energy demand appreciably. Merely the air flowing through the stream of material entering needs to undergo aspiration which is due to sifting-air recycling which at the same time contributes to reducing the hulling-related aspiration air demand by approx. 60%. Consequently, small-size fans can be applied whereby power consumption is reduced by 23% (Figure 3).

ENERGY [kW/t]
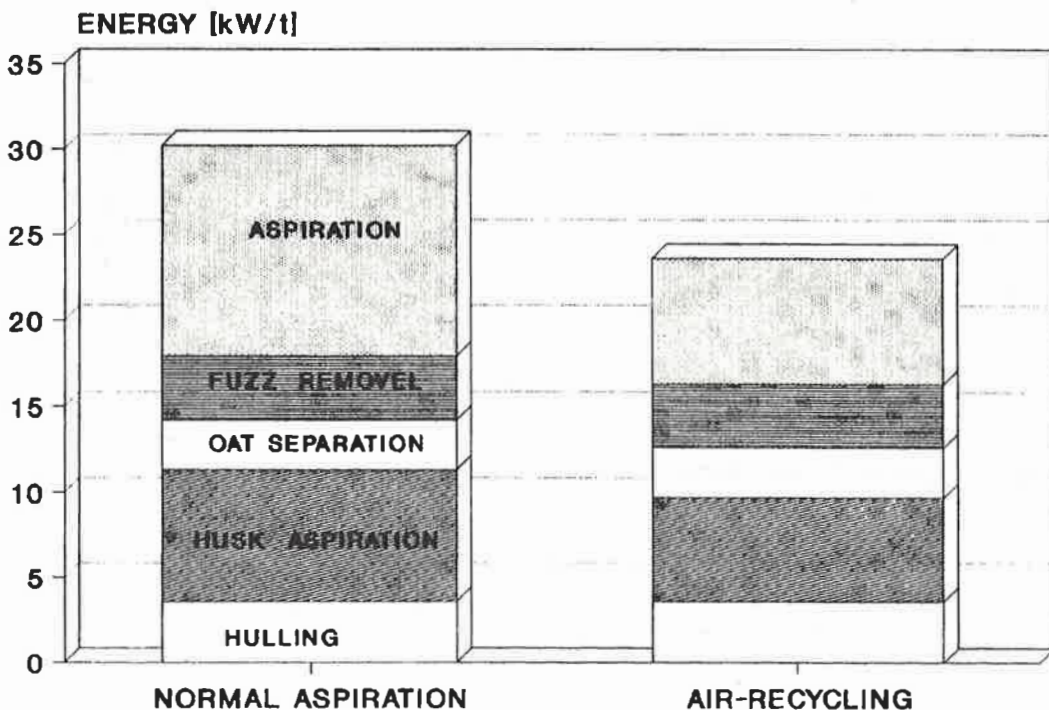
Figure 3.   **Energy Reduction by Air-recycling System** — Hulling Section

Process Automation

Today's possibilities offered by state-of-the-art electrics and electronics permit monitoring and control of autonomous machines, process operations and processes. The production of flakes may serve as an example: Prior to passing through flaking, the groats are fed into a steam conditioner to undergo direct-steam treatment. The aim is to make groats deformable and to give them the required toughness just before guiding them to pass through flaking to the requested thickness (Figure 4).
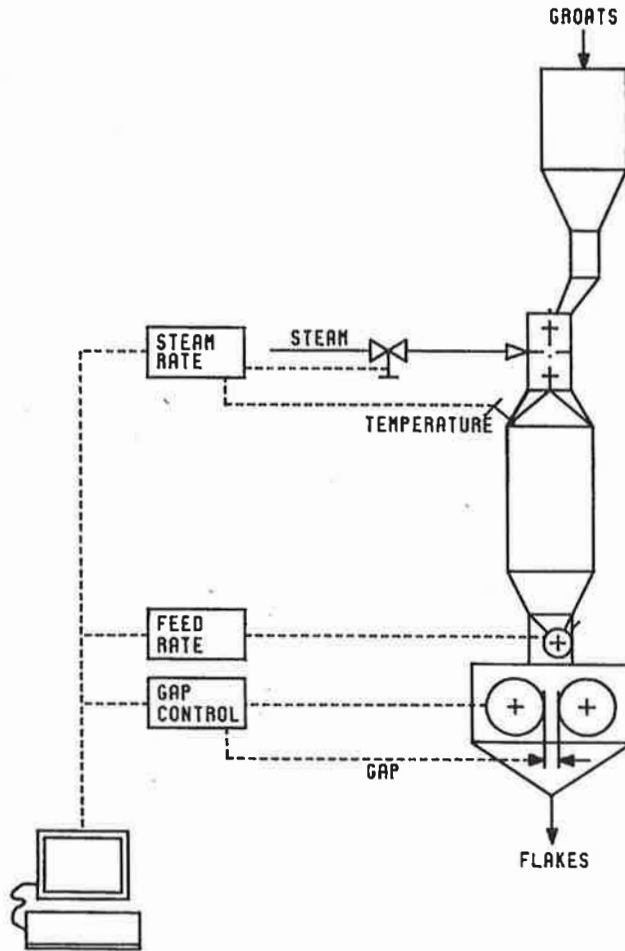
Figure 4.   **Process Automation** — Flaking Section

A feeder mounted on top of the flaking roller mill serves to ensure uniform product feed.

The rate of steam added is automatically controlled as a function of product temperature. The roll gap is set to match the required flake thickness. In case of any unintentional variation during operation, the roll gap is set to match the required flake thickness. In case of any unintentional variation during operation, the roll gap is automatically brought into its preset position. This greatly contributes to making the flaking plant easy to operate whereas the operators may in particular attend to product quality.

Producing Specialty Products

The production of nonconventional oat foods is frequently associated with new technologies to be developed. It may serve as an example to mention that hitherto nonpractised techniques have been used in oat milling to produce oat foods with a high content of soluble dietary fiber and Beta-Glucan.

In the course of tests, endosperm cell walls were found to locate Beta-Glucan which deposits particularly concentrated in cell walls of the subaleurone layer[3]. Consequently, the object was to separate these grain layers, thereby relieving the cell walls largely of cell constituents protein and starch.

By applying appropriate crushing and screening machines it will be possible to produce oat products mainly from peripheral groats layers with double the content of dietary fiber and Beta-Glucan. Additional concentration may be obtained by passing oat bran to undergo further fractioning (Figure 5). Preceding extraction of fat from oats will even increase the yield of Beta-Glucan since fat-extracted flour particles are likely to be more easily separated from the cell walls[4].

In the course of divergent tests[5] it was found that Beta-Glucan contained in the raw material also has a decisive effect on absolute Beta-Glucan values attained.

SOLUBLE D.F.   TOTAL D.F.

DIETARY FIBER [% d.b.]

FRACTION	<0.2	0.2-0.35	0.35-0.5	0.5-0.8	0.8-1.25	1.25-1.5 [mm]
YIELD	1.9	9.1	6.5	8.6	3.0	0.6 [%]
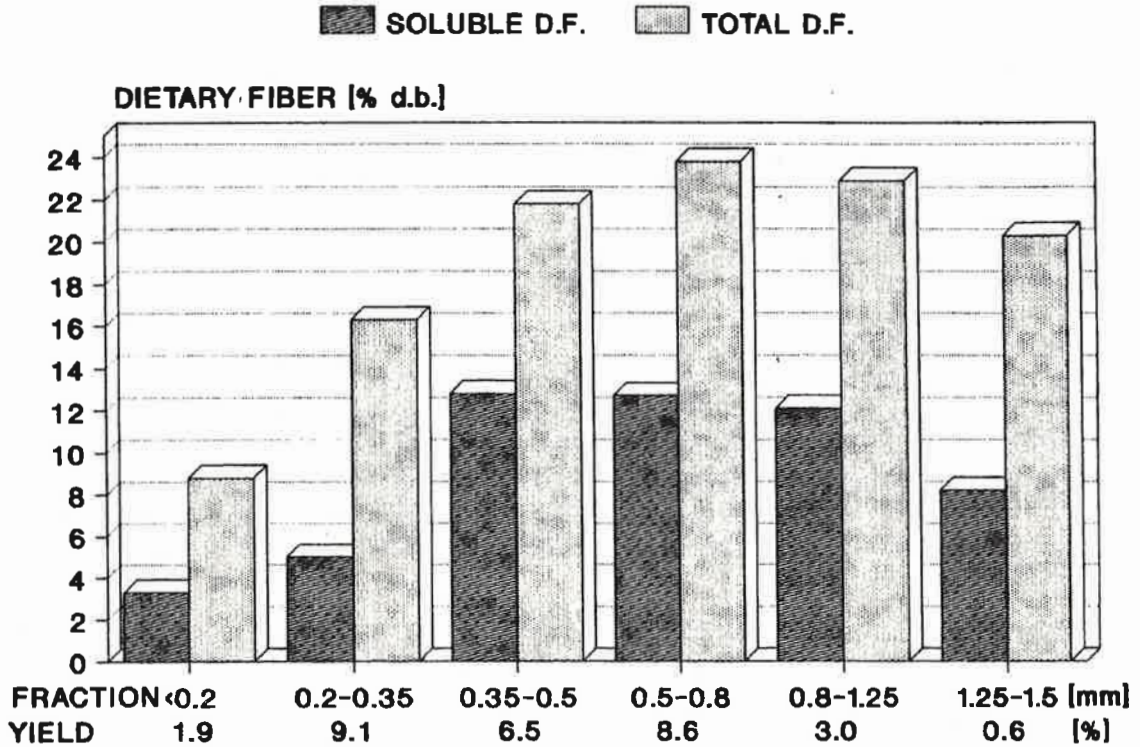
Figure 5.   **Fractioning of Oat Bran**

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The Development of Naked Oats in the UK

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Summary

There seems no major barrier to the future improvement of naked oats or to uptake in various markets in UK. The initial route to commercialisation has proved to be via several specialised markets. Ultimately, naked oats could replace imported protein and energy ingredients in general animal feeds, the potential for which was indicated by Doyle and Valentine[4].

Introduction

The grain of naked oats (huskless or hull-less oats), like that of domesticated wheats, threshes free from a non-lignified lemma and palea. Genetic removal of the husk, which is also a major source of variability in husked oats, dramatically improves levels of nutrients and metabolisable energy content. Naked oats are particularly well suited to feeding to non-ruminants, such as pigs and poultry, which have limited ability to cope with fibre. The grain has a higher specific weight than oats, an important consideration from storage and transport viewpoints and is better suited to certain markets than mechanically de-husked oats.

Naked oats were grown in Britain as early as the middle of the 16th Century, but modern varieties have been derived from genetic sources native to China, Tibet and Asiatic Russia. A form called Chinese was first introduced to the USA in the first half of the 19th Century. The unimproved oats yielded less than half of the levels of then available husked oats and were inevitably weak-strawed and disease-susceptible.

Stanton[11] described the extravagant claims that travelling salesmen made to 'gold-brick' unfortunate purchasers of completely unadapted naked oats in the USA, particularly in the Bohemian oat scandal (1870–1880). In contrast, commercialisation in the UK followed from:

1)   the development of economically acceptable oats,

2)   circumventing the seed production problem,

3)   a clear and honest appraisal of chemical composition, yield, gross margins and other characteristics such as drying and storage coupled with

4)   the identification of specialised markets.

This paper seeks to examine the some of these aspects particularly from a genetic improvement viewpoint, while Richard Mason in a later paper will outline the commercial development of naked oats in the UK and describe existing and future markets.

Recovery of High Groat Yield and Other Characteristics

Most naked oat varieties trace to Chinese naked and the variety Laurel (Banner x Chinese naked) bred at Ottawa and released in 1930. Laurel was a parent of the French variety Nuprime[9] and the naked source of the IGER-WPBS programme initiated in 1971 (Figure 1). On the basis that each hybridisation of a naked and husked oat results in a 50% reduction on average of the number of genes from either parent, the spring variety Rhiannon (added to the UK National List in 1984) contains 6% of genes from Chinese and the winter varieties Kynon (1986) and Pendragon (1991) only 3%. Accordingly these varieties have groat yields and agronomic characteristics similar or nearly so to the most widely grown husked oats, also released in the '80s.

Kynon and Pendragon are six hybridisations (actually only five cycles of hybridisation and selection) away from Chinese which was introduced in the early 19th century. Even allowing for the fact that hybridisation of oats only began in earnest in the 1900's, this is a slow rate of improvement which we can clearly improve in the future. For example, using the 'accelerated pedigree method'[14, 15] following an initial cross made in 1979, the Kynon segregate was used four years later to initiate a further cycle of selection and hybridisation, a product of which is in National List trials this year (1992).

Selection for High Naked Expression

At the hexaploid level, naked oats are fully inter-fertile with husked A. sativa types. The naked character is controlled by a single dominant gene, N-1[10] together with a small number of modifying genes. Both facts point to the correct classification of naked oats as A. sativa var. nuda and to the ease with which it should be possible to transfer desirable characteristics from husked to naked oats. In view of the facts that a small but variable proportion of naked grain are released from 'hardened' lemmas[1] and that the expression of nakedness also varies with environment[5, 8], the genetic models proposed by Moule[9] Clamot[2] and Jenkins and Hanson[6] which postulated two or three modifying genes of varying dominance and epistatic effects may be rough rather than precise guides to the exact biological situation.
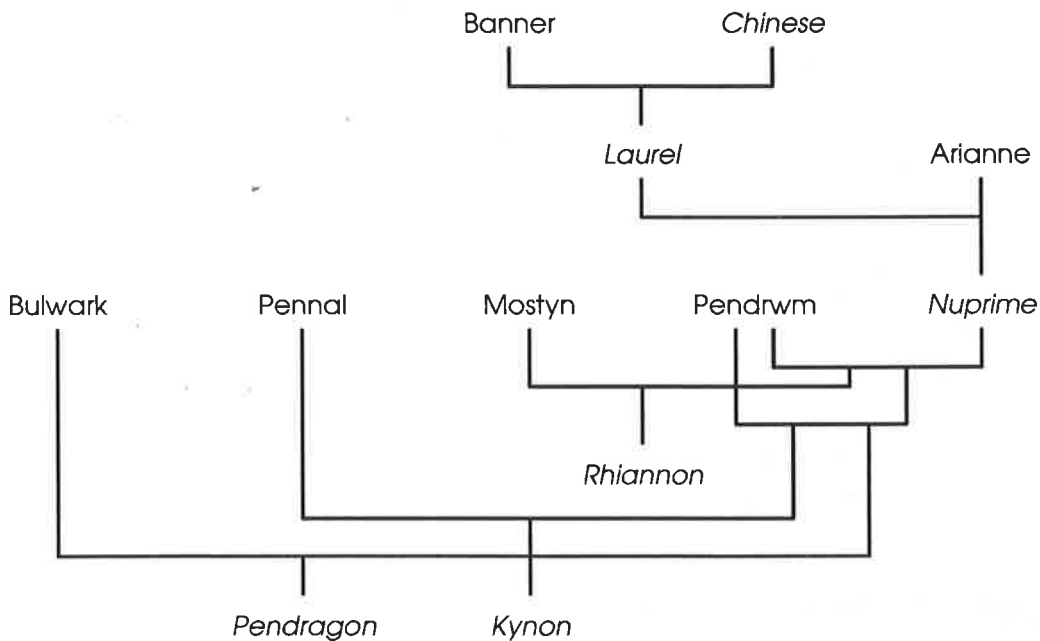
Figure 1.   Development of IGER-WPBS naked oats
                                 Naked oats are indicated in *italics*.

For breeding purposes, segregation for the degree of nakedness is effectively continuous. We seek fully or nearly so naked types and avoid intermediate types especially 'phenotypic mosaics' with a high proportion of husked grain particularly in the basal whorls of the inflorescence. The multiflorous habit (a pleiotropic effect of N-1) and the soft feel of the spikelets are of enormous help to selection for high naked expression. While Kynon and Pendragon have a much higher naked expression (96-99% by number) than the spring oat Rhiannon (around 90-95%), 100% naked expression has not yet been achieved and the variation in this character is unpredictable. We find that the multiflorous habit, while an aid to selection of high naked expression, is however a hindrance to the visual assessment of the important yield components groat size and number.

Chemical Composition

Comparisons of the composition of naked oats and other small grain cereals in the UK have been summarised by Valentine[16]. As expected, Naked oats had much less fibre (86-141 g/kg DM NDF) compared to oats (283 g/kg) and barley (234 g/kg). Oil content (83-114g/kg DM) was superior to oats (43 g/kg), wheat (19 g/kg) and barley (13 g/kg). Since oil contains 2.25 times as much energy as carbohydrate on a weight for weight basis, naked oats have a higher metabolisable energy (e.g. digestible energy for pigs = 16.0 MJ/kg DM) than wheat (14.7 MJ/kg) and barley (13.0 MJ/kg).

Protein is more variable than oil content, but due to higher levels of essential amino-acids in the protein, naked oats have higher levels of lysine and methionine and cystine taken together than either wheat or barley.

On the basis of 'book' values of chemical composition and the nutrient requirements of stock, Doyle and Valentine[4] used least cost formulation to calculate the true nutritional value of naked oats for pigs and cattle. As expected, calculated prices/t were above those of wheat and barley, particularly for feeding to pigs. When the lower variable costs of growing oats were taken into account, the estimated gross margin for winter naked oats was above that of winter barley, but not winter wheat, while the gross margin for spring naked oats was below that of spring barley.

The stage has been reached where a significant effort aimed at modifying the chemical composition of naked oats could be justified. On the available evidence, it seems that it will be easier to increase oil rather than protein content.

Resistance to Threshing

The initial development of naked oats in the UK was held back by the failure of some (NOTE: *only some*) seed crops to meet the official germination standard of 85%. This is due to naked oats being more susceptible to threshing damage. The grain is softer than that of wheat and barley and has a protruding angled embryo radicle. No real resistance to threshing was identified by von Kittlitz and Uhlig[7] nor Thornton[13]. Valentine and Hale[17] showed, that while an experimental stripper combine harvester with pre-separation of grain resulted in satisfactory germination, commercially available combines reduced germination below 85%. However, it was shown that differences in germination could be economically compensated for by simply increasing seed rate. This information formed part of a successful case for the amendment of the EC Seeds Directive to allow seed of naked oats to be sold at 75% germination. Economic seed production proceeded — though with care.

Freedom from Groat Discoloration

Black discoloration, usually at the 'brush' end of the groat, is mainly caused by *Alternaria alternata* and *A. tenuissima* [12]. Severe infections darken the grain, diminishing its premium value. Germination is also reduced. Discoloration is generally worsened by high humidity during grain development[12].

We have used artificial inoculation tests to screen for genetic differences in groat discoloration quantified as:

- ☐ Number of grains with no blackening in two 25 grain samples =c_1
- ☐ Number of grains with 0-50% blackening x 2 =c_2
- ☐ Number of grains with 50-100% blackening x 3 =c_3
- ☐ Number of grains with 100% blackening x 4 =c_4
- ☐ $c=(c_1+c_2+c_3+c_4)/50$

The theoretical range is from 1 (all grains clean) to 4 (all fully discoloured).

Kynon has proved to be one of the least discoloured winter naked oat varieties (mean c from 1988 to 1991 = 1.79), not significantly different from the most widely grown husked winter oat, Image (mean c =1.87). Likewise, Rhiannon was one of the least affected spring naked oats (mean c from 1989 to 1991 = 1.77), being better than Dula (mean c = 1.85), the most widely grown spring oat. These values reflect the fact that groat discoloration has not been any more of a problem than in husked oats, but nevertheless is a characteristic which needs improvement.

Apart from assessing varieties and advanced lines, a collection of 146 naked oats of diverse origin has been screened. No absolute or very high levels of resistance have been identified[3].

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Naked Oats — An Alternative Energy Source for Performance Horses

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Summary

Four thoroughbred geldings were used in a 4 x 4 Latin Square design digestibility trial to determine the nutritive value of naked oats and their effect on overall ration digestibility. Four molassed diets were fed containing different proportions of alfalfa and naked oats: 100:0, 80:20, 60:40 and 40:60, respectively. Dry matter intake was relatively constant at 1.9% of liveweight and the rations supplied from 150 to 205% of maintenance energy needs. Replacement of alfalfa by naked oats increased (P < 0.01) digestibility of gross energy, organic matter and fat and decreased (p < 0.05) protein digestibility. The nutritive value of naked oats determined by both regression and difference was 16 MJ digestible energy and 82 g digestible crude protein kg^{-1} DM. The results are discussed in relation to meeting the requirements of the performance horse.

Introduction

Oats have generally been regarded as a major component of the working horses' diet. Daily oat allowances for different types of working horses were: cavalry 4.5 kg; hunters 6.5 kg; racehorses 6.75 kg; carriage horses 6.25 kg and cab horses 8.5 kg[1]. The recommended daily oat allowance for a working farm horse at the beginning of the 20th century was 5.5 kg and the power available to the farm labour force was about one horsepower (745 watts) per man[2].

Oats are a traditional feed for horses and, of the cereals available, they are preferred by horses as evidenced by preference testing[3]. However, there is some concern over the feeding of fresh oats since it has been reported[4] that horses fed freshly-harvested oats often colic and are more lkely to sweat and become exhausted more easily. t is advised that oats should be stored for two to three months prior to feeding[4]. Others[5] have stated that "new" oats should not be fed and more recently, it was suggested[6] that "new" oats should be stored at least 5 months prior to feeding. The need for the storage of "new" oats remains to be tested, although 'new crop' naked oats have been fed to racehorses without any subsequent problems (Cuddeford, personal observation).

A recent (1990/91) survey amongst racing yards in the Newmarket and Lambourn areas of the UK, covering about 10% of horses in training, has shown that 80% of trainers feed oats (Cuddeford, unpublished data). Of these, approximately half feed oats alone and the other half feed oats in combination with a commercially produced complete pellet/coarse mix or balancer.

Racehorses weigh between 430 kg (sprinters) to 520 kg (National Hunt horses) and are fed up to 9 kg conventional oats daily (Cuddeford, personal observation). The ingestion of large quantities of cereal starch have been associated with metabolic problems such as colc and laminitis[7] and, if the total daily starch intake can be reduced and/or r eplaced with alternative "safe" energy sources then the racehorse will be at less risk of digestive disturbance. Since food intake is often limiting in these animals, energy-dense alternatives to conventional oats would be extremely useful in their diets. Naked oats are a concentrated source of nutrients due to the absence of husk and presence of oil and this paper describes work carried out to evaluate their potential feed value for performance horses.

Methods

Animals

Four mature thoroughbred geldings (mean weight 543 kg) were bedded on shavings and kept in 3.5 x 3.5 m loose-boxes or rubber-matted stalls. The animals were exercised daily between 09.30 and 11.30 and between 14.30 and 16.30 h using a rotary horsewalker set at a comfortable walking speed (up to 1.67 m/s). Horses were weighed daily prior to morning exercise.

Diets

Dried, molassed, precision-chopped alfalfa formed the basal diet and was rationed to provide 150% of maintenance based on the following equation[8], DE (MJ/day) = 4.184 (1.4 + 0.03W), where DE is digestible energy and W is the liveweight (kg) of the horse. The other diets were obtained by substituting naked oats (var. Rhiannon) for 20, 40 and 60%, weight for weight, of alfalfa. Thus, each horse received the same quantity of fresh food irrespective of treatment and the diet containing 60% naked oats supplied about 205% of the maintenance energy need for each horse. The daily ration was divided into four equal feeds and fed at 07.00, 12.00, 17.00 and 22.00 h; water was available *ad libitum*. Any feed refusals were collected prior to the 07.00 feed. The composition of the experimental diets is shown in Table 1.

Table 1. Nutrient composition of experimental diets (g kg^{-1}DM).

Alfalfa (%)		100	80	60	40
Naked Oats (%)		0	20	40	60
Organic Matter	(OM)	907	921	936	951
Crude Protein	(CP)	172	164	157	149
Ether Extract	(EE)	24	36	48	60
Acid Detergent Fibre	(ADF)	299	248	194	141
Neutral Detergent Fibre	(NDF)	389	330	269	208
Calcium	(Ca)	16.1	13.4	10.6	7.7
Phosphorus	(P)	2.5	2.8	3.1	3.4
Magnesium	(Mg)	3.4	3.1	2.7	2.3

Experimental Design

A 4 x 4 Latin Square design was employed using 4 horses, 4 diets and 4 periods. Each period lasted 21 days and was composed of 14 days adaptation followed by a 7 day collection period. An incomplete collection was made during the first 4 days of each collection period, faeces being sampled after each exercise period whilst animals were resting in stalls, standing on rubber mats. A complete collection was made over the last 70 h of the period in the stalls to facilitate rate of passage measurements.

Statistical Analysis

Digestibility data were subjected to an analysis of variance using the Genstat V (release 1:2) statistical package[9], followed by Students' 't'-test to determine the significance of the difference between treatment means. Rate of passage data were analysed by fitting curves of faecal chromium concentration against time and regressing the natural logarithms of the slopes to determine the gradients, which were then compared by an analysis of variance.

Measurements

Digestibility of nutrients was estimated by measuring dry matter (DM) intake and determining the content of acid-insoluble ash (AIA) in the dietary DM and in the faecal DM. AIA has been shown[10] to be a reliable marker for estimating the apparent digestibility coefficients of nutrients fed to horses.

Rate of passage was measured over the last 3 days of each collection using chromium-mordanted hay as a marker; the hay was mordanted according to established methods[11]. 20g of mordanted hay was mixed with a little molasses and fed to each horse at 22.00 h prior to the last feed on day 4 of each collection period. Faecal output from each horse was collected every 10 h, weighed, well-mixed and a 10% sample taken. This process was continued for 70 h after the initial feeding of mordanted hay. All faecal samples were stored at -20°C until the end of the period when they were thawed and dried to constant weight in a forced-draught oven at 60°C. The chromium content of the samples was determined by atomic absorption[12].

Feeds were sampled daily and stored at room temperature until the end of each collection period when they were bulked, mixed, sub-sampled and dried. The feed and faecal samples were analysed for gross energy (GE), acid-insoluble ash (AIA) and crude protein (CP), according to published methods[13].

Acid-detergent fibre (ADF) and neutral detergent fibre (NDF) were estimated[14,15] and ether extract (EE) was determined following acid hydrolysis[16].

Results and Discussion

Digestibility Data

The effects of substituting naked oats for alfalfa on the apparent digestibility coefficients of ration nutrients are summarised in Table 2. All horses had some feed refusals, suggesting that they were at the limit of intake when fed these particular diets.

Increasing the level of naked oats in the ration significantly ($p < 0.01$) improved the apparent digestibility of OM, GE and EE in keeping with expectation. There were incremental increases in these digestibility coefficients at each inclusion level of naked oats. The increases between 0 and 60% and between 0 and 40% were all significant although differences between 0 and 20% were only significant for OM and EE. Differences between 20 and 60% and 40 and 60% for the digestibility coefficients for GE were significant.

A negative correlation between digestibility and dietary fibre content has been demonstrated in horses[17]. As the content of naked oats increased in the ration from 0 to 60%, the ADF content (g kg^{-1} DM) was progressively reduced from 299 to 141 (see Table 1) and consequently digestibility improved. Others[18] have observed similar effects using crimped, husked oats in place of long-stem alfalfa hay (395 g ADF kg^{-1} DM). The oats supplied 0, 20, 40, 60 and 80% of the DE requirement for maintenance and the apparent digestibility coefficients for DM, GE and EE improved from 0.54, 0.51 and 0.15 to 0.60, 0.60 and 0.77 respectively. The large improvement in the value for EE was not reflected in the current study where dietary EE content (g kg^{-1} DM) increased from 24 to 60 compared to 19 and 48 in the conventional oat study. The authors of the latter study suggested that low coefficients measured in horses fed high roughage diets could have been due to the low dietary EE and increased faecal losses.

The crude protein was uniformly highly digestible in diets containing 0, 20 and 40% naked oats but was less digestible ($p < 0.05$) in the diet containing 60% oats compared to the others. This difference may be partly explained by the fact that the addition of conventional oats to an alfalfa hay diet has been reported[18] to have a negative associative effect on dietary CP digestion. Furthermore, the reduction in dietary crude protein intake by animals fed the 60% naked oat diet would be associated with a reduction in apparent digestibility since faecal endogenous losses would be of greater significance.

Table 2. The effects of substituting naked oats for alfalfa on the mean apparent apparent digestibility coefficients of ration organic matter (OM), gross energy (GE), ether extract (EE), crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF).

Alfalfa (%)	100	80	60	40	SED	F ratio	't'-test
Naked oats (%)	0	20	40	60			
OM	0.63	0.71	0.75	0.76	0.032	**	** ** *
GE	0.60	0.63	0.67	0.72	0.019	**	*** ** *
EE	0.27	0.42	0.53	0.54	0.054	**	** ** *
CP	0.75	0.78	0.75	0.67	0.030	*	* * *
ADF	0.33	0.42	0.37	0.40	0.089	NS	
NDF	0.36	0.44	0.43	0.43	0.056	NS	

⌐_⌐ = treatment comparisons; NS = nonsignificant difference;

** = p<0.01); * = p<0.05

Although fibrous components of the alfalfa were digested less well than those in the mixed diets, there were no significant differences and no apparent trends. Others[18] have shown that digestibility coefficients for ADF have decreased ($p < 0.05$) as the proportion of oats in the ration has increased. This contrasts with experiments[19] where increasing the proportion of maize in the diet was associated with an increase in the digestibility of ADF. It has been proposed[18] that these differences may be explained on the basis of the nature of the fibre fed. The extent of lignification affects fibre digestibility and it is suggested[18] that the high lignin content (61 g kg^{-1} DM) of the husked oats contributed to the reduction in fibre digestibility. Naked oats are low in lignin (16 g kg^{-1} DM), although not as low as maize (6 g kg^{-1} DM)[20], and might be expected to be associated with an improvement in fibre digestibility similar to that reported elsewhere[19].

Rate of passage

As the naked oat content of the diet increased there appeared to be a trend toward increased rate of passage however, in contrast, the 60% oat diet had the slowest rate of passage (Figure 1); none of the differences were significant (Table 3). Unfortunately there is a lack of available data for comparative purposes although ordinarily, one would expect that the transition from a roughage-only diet to a concentrate-based diet, without the complication of a changed feeding level, to be associated with a more rapid rate of passage. This would reflect the change in digestion site from the caecum/colon to the stomach and small intestine where most of the available carbohydrate would be digested[21].
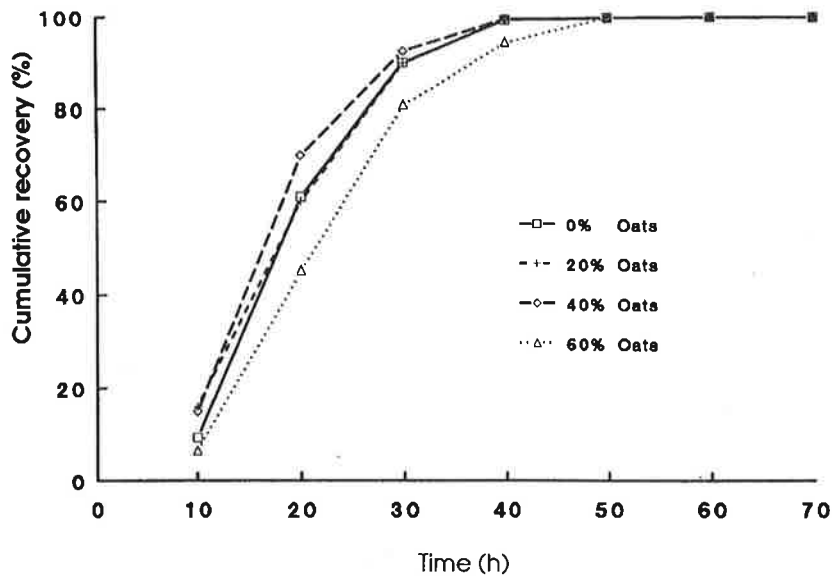
Figure 1.   Mean Cumulative recovery of Chromium for the Treatment Diets

Table 3.   The effects of substituting naked oats for alfalfa on the mean values
for rate of passage (slope), faecal output (kg d^{-1})
and faecal dry matter content (g DM kg^{-1}).

Alfalfa (%)	100	80	60	40	SED	F ratio	't'-test
Naked oats (%)	0	20	40	60			
Rate of passage	0.098	0.115	0.125	0.093	0.029	NS	
Faecal output	24.6	21.5	20.9	16.8	1.389	* *	**
							*
							*
Faecal dry matter	225	228	205	195	10	*	
							*
							*

⌊____⌋ = treatment comparisons;   NS = nonsignificant difference;

** = p<0.01);   * = p<0.05

The increase in OM digestibility associated with the increased content of naked oats is reflected by the reduced faecal output (p < 0.01); there was a reduction for each increment of oats inclusion. Furthermore, the water content of the faeces was related to the inclusion level of naked oats (p < 0.05) and in most cases there were incremental increases in water content with each addition of oats (Table 3). This could be a reflection of the changes in proportion of fibre types; alfalfa contains little hemicellulose, which is known to retain water, and alfalfa-fed horses produce drier faeces[22]. The progressive replacement of alfalfa with naked oats would decrease the hemicellulose content of the diet from 90 to 67 g kg^{-1}DM and thus less water would be held in the lumen of the gut producing drier faeces. Oat ß-glucans have been associated with "sticky" faeces produced by poultry[23] and perhaps they could contribute toward the low dry matter of the faeces produced by the horses fed the 60% naked oats diet.

Nutritive value of naked oats

It is not feasible to determine the nutritive value of grains directly by feeding them alone to horses. In most cases, the values are determined by difference[24] or by regression where several different levels of cereal inclusion are used. The underlying assumption is that the value of a ration is the sum of its component parts and that the contribution of each component is the value obtained when it is fed by itself. The apparent digestibility coefficients of naked oat nutrients estimated by the two methods are shown in Table 4 and it is apparent that the values obtained show close agreement. The resultant digestible nutrient content (g kg^{-1}DM) of the naked oats used in the current study was: CP, 82; OM, 847; NDF, 38.5 and ADF, 13.5. The composition of the naked oats used in the current study is compared with other published data in Table 5 and digestible energy (DE) values determined *in vivo* are compared with calculated values based on ADF content[26]. The equation used by the National Research Council (NRC) Subcommittee on Horse Nutrition (4.184 (4.07 - 0.055 (% ADF))) provides estimates of DE which are close to those obtained *in vivo*. The more recently developed equation[26] overestimates DE values by as much as 119% for naked oat varieties.

Table 4. The apparent digestibility coefficients of the organic matter (OM), crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) of naked oats estimated by difference or multiple linear regression.

	Difference	*Multiple linear regression*
OM	0.87	0.87
CP	0.64	0.64
ADF	0.42	0.43
NDF	0.46	0.47

Table 5. The nutrient composition (g kg^{-1}DM) of husked and naked oats and their energy values (MJ kg^{-1}DM).

Oat type	Ref.	CP	NDF	ADF	GE	DE[1]	DE[2]	DE[3]
Naked (Winter)	(20)	147	76	32	19.9	16.3	18.7	
Naked (Spring)	(20)	123	123	44	20.1	16.0	18.3	
Naked (var. Rhiannon)	this study	128	84	32	20.1	16.3	18.7	16.0
Naked (var. Pennuda)	(25)	182	155	37[4]	18.4	16.2	18.5	15.5
Husked (USA)	(25)	128	342	163[4]	18.4	13.3	13.5	12.5
Husked (UK)	(20)	108	310	149	19.6	13.6	14.0	

[1] calculated value, DE = 4.184 (4.07 - 0.055 (%ADF))[26]
[2] calculated value, DE = 4.184 (4.78 - 0.095 (%ADF))[26]
[3] *in vivo* value
[4] calculated values[27]

However, in spite of these differences, it is obvious that naked oats are a concentrated source of digestible energy for the horse and are equivalent to maize in this respect. They contain 128% of the digestible energy of husked oats (Table 5) and thus 0.78 kg naked oats can replace 1.00 kg husked oats on a dry matter basis in rations for horses. Typical usage of naked oats by National Hunt Horses in the UK is shown in Table 6 and it will be apparent that the oats provide quite a large proportion of the energy (0.56) and protein (0.54) in the ration. If husked oats were used, 8.18 kgs would have to be fed to provide the same amount of energy as the naked oats; the husked oats would supply about 3.4 kg of starch daily compared to 3.3 kg from the naked oats. Thus, the reduction in starch intake is small and the major benefit of using naked oats in racehorse diets will be that it is possible to meet energy needs with a reduced volume of feed.

Table 6. Contribution of naked oats to digestible energy (MLDEd^{-1}) and protein (gCPd^{-1}) requirements of a typical racehorse in the UK. "Waterloo Boy" — 520 kg gelding in full training (trained by D. Nicholson)

Daily ration (kg as fed basis):		Nutrients Supplied:		
		DE		CP
Naked oats	6.36	90		716
Coarse mix	0.23)		)	
Vegetable oil	0.18)	70	)	600
Grass hay	6.36)		)	
Totals	13.13 (2.5% of liveweight)	160		1316
Requirements[28]	13.64	142		1358

Associative effects

It has been claimed[29] that feeding level has no significant effect on diet digestibility and that forage digestibility was unaffected when different proportions of concentrate were provided. Furthermore, it was suggested that measurements of concentrate digestibility made at maintenance levels of feeding could be applied to horses fed above maintenance provided the digestibility of accompanying roughages were measured simultaneously. However, other work[18,30] suggests that feeding level and forage/concentrate interactions may be important. Significant differences have been measured[18] between observed and expected digestion coefficients for CP, EE and acid detergent cellulose in horses fed varying hay/grain ratios at maintenance. Figure 2 shows a non-linear increase in the digestibility coefficients for gross energy in the current study; the value for 60% naked oats is higher than would be expected and this correlates with the reduced rate of passage of this diet. Other work (Cuddeford, unpublished data) using similar inclusion levels of rolled, husked oats or cooked or uncooked naked oats has shown that, knowing the digestibility of the roughage component, the apparent digestibility coefficients obtained (using the difference method) for the cereals were unrealistically high. These findings suggest that there may be a synergistic interactive effect between the oats and roughage at high inclusion levels of oats. Previous work[29] that indicated no interaction between roughage and concentrate was in horses fed at maintenance, 1.4 times maintenance and *ad libitum* fed animals.

The latter group of horses were fed no higher than 1.98 times maintenance which in practice was similar to the current study where the 60% naked oats diets supplied about 2 times maintenance. It is postulated that at high levels of naked oat inclusion the digestion of the roughage is enhanced which in part would probably be due to a slower rate of passage.
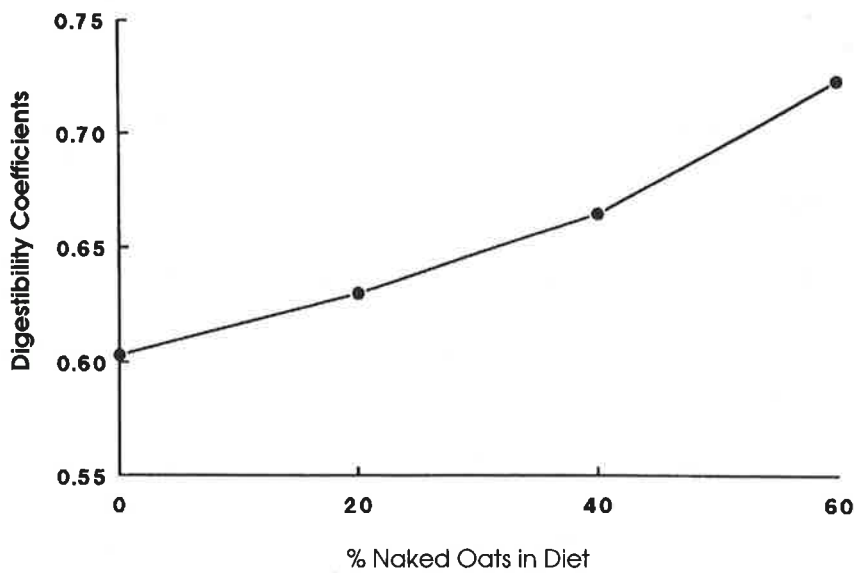
Figure 2. The Apparent Digestability of Gross Energy in Diets containing Different Proportions of Naked Oats.

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Naked Oats — A Commercial Reality

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Introduction

Naked Oats a commercial reality. Along with many before us, we learnt it takes more than commercial logic to create a financial success.

A form of Naked Oat was recorded as being grown in Britian during the middle ages, however, modern varieties have been bred from seed collected from China, Tibet and Russia during the last century.

The Welsh Plant Breeding Station began a breeding programme in the 1970's and the resultant varieties that emerged seemed to have some commercial promise.

Having first secured product source, we then identified a number of benefits that make Naked Oats attractive to growers:

- A cereal break crop allowing growers to reduce take all levels and diseases in a cereal rotation.
- No requirement for high levels of inputs to achieve good financial returns.
- An unexploited market.
- An opportunity for contract production providing security to the grower, and market control.

Formation of the Superioat Company Limited

In 1986 the Superioat Company Limited was formed as a joint venture between two companies who believed there was considerable potential in the development and marketing of Naked Oats.

The Company decided that if Naked Oats were to be a success then a specialist approach, engaging activities specific to the crop and its markets, was essential.

Initially the Superioat Company undertook the growing of test areas of both winter and spring varieties. The success of these crops not only provided a launch pad for wider commercialisation, but also an insight to the growing and handling requirements of Naked Oats.

During this development period all crops were surveyed and the grain analysed. This enabled the Company to support farmers with information based on growers own experiences.

The future of Agriculture looked bleak. Overproduction and the increasing cost of subsidies meant that productivity policies were doomed. In America production controls were some years old. In Australia and New Zealand subsidies were history. A low cost, market led premium crop was a logical option. However, it is easy to be blinded by enthusiasm, where we believed there were opportunities, attitudes of the consumers and ignorance of the product meant we encountered an immediate reluctance.

In many respects Naked Oats are similar to groats. They do however have unique properties and some differences which gave rise to initial suspicions. For instance the high levels of oil found in Naked Oats has led to concern being expressed on the development of hydrolitic rancidity in Naked Oats during storage. In Superioat Company trials undertaken on commercial storage, it has been found that, provided the oats are dried to 14% rapidly after harvesting, and good storage methods are practised, no significant deterioration will take place.

Market Development

Most of our current research has been directed at market development. However, considerable attention has been paid to the agronomics of the crop to ensure that growers maximise their returns.

Variety trials are conducted in both the UK and other European countries to assess yield and quality of existing and new varieties from across the world. In addition, a comprehensive agronomy trial covering sowing rates, seed treatment, fungicides, fertiliser usage and harvesting methods, are conducted annually.

To overcome the problems the Superioat Company concentrated on a process of education through research and development to overcome the suspicions and fears of producers and buyers. As crops need to be grown and marketed we embarked on a two pronged approach; agronomy and utilisation.

The research and development programme began by commissioning the Governments Agricultural Advisory Service to develop a comprehensive guide on the growing, harvesting and storage of Naked Oats. This was supported with regular and timely newsletters being sent to every grower.

Colour is important in human consumption usage. Grain discolouration or blackening was a preceived problem. A survey of samples indicated that *Alternaria alternata* and *Alternaria temussima* were the main fungi, but blackening may be worsened by the interaction with other fungi. Whilst no fungicidal control has yet been found, the winter variety Kynon, has been shown to have better genetic resistance than Image, the most popular conventional oat being grown in the UK. Plant breeders will therefore be breeding for better genetic resistance to these fungi in the future. The Company continues to investigate this subject in field trials.

Naked Oats have trichomes or hairs attached to the surface which are released during threshing and handling. Our trials have shown that the correct combine settings can allow many of these hairs to be removed during thrashing, thus reducing problems during handling.

We continue to research into these areas as we believe we are still on a learning curve.

With the probability of lower grain prices in the future, the importance of grain premia will be that much more significant to the profitability of a cereal crop. As Naked Oats yield approximately 20-25% lower than conventional oats in the UK, they have to attract a compensatory premium. However as the groat yields of Naked Oats may be similar to the best achieved from milled (dehusked) oats, cost savings are therefore possible in transport, storage and processing. Agricultural commodity prices can be expected to decline but the cost of transport, processing and energy will increase. As a result, the cost/benefits of Naked Oats compared to covered oats will improve. This in turn may make the Naked Oat increasingly attractive to consumers be it in animal, human or industrial markets.

The equine market has always had a high regard for oats in rations. The advent of commercial quantities of Naked Oats offered a new alternative feed for the competetive horse. Dr Derek Cuddefords' paper will deal with this sector in some details.

In the human consumption market the recent global awareness on the health aspects of good diet has increased the consumption of oats. The uptake of Naked Oats in this sector whilst initially slow, has begun to pick up considerable momentum both in the UK and overseas. With a quality product increasingly available it can be expected that there will be sustained growth as the costs of handling and removing husks from covered oats will become proportionately greater relative to the raw material price. Bran extraction can be high from Naked Oats and Malted Naked Oats are now used in bread baking and biscuits in increasing quantities. This market will continue to grow.

A significant emerging market for Naked Oats is the pet food industry. The low fibre content and high quality grain of the Naked Oat, particularly in respect to lysine and higher oil levels than other cereals, makes it an easily digestible feed for a wide range of pets. Therefore there is considerable potential in this market.

Within the pet food market there has been a dramatic increase in dry complete foods and recent notable success has been achieved in launching muesli based products. It appears that even in a recession, owners are reluctant to spend less on their pets. The Superioat Company's work and investigations continue on this market and with a single European Market in 1993 there is a considerable prospect offered to UK pet food manufacturers. These studies include whole grain work in addition to flaked, micronised and extruded Naked Oats across a wide range of pets and companion animals.

In the autumn of 1991 the Superioat Company in conjunction with the plant breeding company Semundo, commercially extruded oil from Naked Oats. As far as we know, this may be the first time that oil has been extracted at 'commercial' levels from Naked Oats. Currently, and in association with a number of research and food organisation, the Superioat Company is undertaking specific and detailed research into the properties and potential of oat oil. It has however, already been revealed that oat oil would appear to have a wide application in a diverse range of markets from pharmaceutical, cosmetics and the food industry as an emulsifier. As a natural 'new' oil source, many more markets will be revealed but this will take a considerable time to develop.

Future Prospects

One of the consequences of lower cereal prices may be that it could open new opportunities for industrial exploitation. The present price of raw material has largely precluded industrial involvement in agro-processing. Lower prices and a greater awareness of renewable sources, coupled with increasing enviromental constraints, could well herald an 'agroindustrial revolution'. Naked Oats could play a significant role in this sector.

Are we ready for that revoloution?

What has clearly been demonstrated over recent years is that in the developed world, markets are becoming more sophisticated. Whilst this creates opportunities for the entrepreneur, it creates a dilemma for the plant breeder who has to take into account the various end market requirements. A simple example of this is that of oil. Where lines with 14% oil content can be selected for the extraction, the same variety may be less well suited where it is to be extruded for pet food.

Such sophistication is not global. The underdeveloped countries of the world face considerable challenges just to feed the hungry. Naked Oats with the addition of water, is a virtually balanced energy providing food. It is easily digestible by the old, the young, the sick and the needy. Should politicians ever think about the subject, then they would soon realise that to export Naked Oats would be preferable to exporting barley.

It is only through single minded pursuit that the Naked Oat crop is now accepted in the UK by both producer and consumer, with some 20,000 tonnes of production this year. With this confidence, the Superioat Company has joined forces with a German company to create the Hana Korn and Kern Company to develop production and markets in mainland Europe.

So in conclusion, we have succeeded through perseverance. Through facing the problems. Understanding our product and reacting to buyers demands. Increasing demand for a better enviroment, spiralling input costs, and the cost of processing secure the future for Naked Oats and the Superioat Company.

The Nutritional Value of Naked Oats in Broiler, Layer and Duckling Diets

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Summary

The value of a number of genotypes of naked oats, in particular the new variety "Bandicoot", has been characterised in experiments with broilers, layers and ducklings. Linear relationships for predicting essential amino acids in naked oats (NO) from crude protein content are given. Experiments are presented showing depressed fat digestibility in young chickens which resulted in a low metabolizable energy (ME) of NO. This is largely overcome by the addition of feed enzymes. Microbial phytase was most effective. Experiments with ducklings (10–21d) showed that NO tended to reduce food intake, hence performance, at levels above 40%. Food intake was improved with enzyme addition. With broiler chickens, pelleting and enzyme addition overcame the adverse effects of NO up to a dietary inclusion of 84%. Layer experiments indicated that NO could be included in diets up to about 50%, beyond which egg production and egg mass declined. Addition of a feed phytase to diets with 70% NO improved production but not significantly so; fish meal (3%) plus enzyme gave significant improvements in egg mass and egg weight compared to no enzyme. Fatty acid profiles of egg lipid from hens on NO based diets were different from a wheat based control diet, with linoleic acid increasing from 10.7% to 15.7% of total lipids.

Introduction

The selection of hull-less or naked oats (NO), particularly for broiler chickens, is attractive because there is no need to remove the hulls mechanically. Protein content of NO is high, its oil content is higher than in other feed grains and it is rich in linoleic acid (about 37% of total lipid).

NO has a comparatively high level of indigestible -glucans. In hulled oats this can vary from 3.1 to 5.9%[11] and can cause viscous digesta in the chicken gut. This may reduce the normal digestion and absorption processes, make the excreta watery and sticky resulting in wet litter. This may down-grade the carcass of broilers[6].

Cave *et al.* [5] found a significant negative correlation between NO inclusion (20-60%) and feed intake, feed efficiency and growth rate of broilers from 1-28 d of age. These workers concluded from subsequent experiments that ß-glucan was the factor responsible for depressing broiler growth by reducing fat absorption. Hulan *et al.* [10] concluded that oat groats at levels up to 60% in starter diets and 80% in finisher diets did not depress growth rate or feed efficiency in broilers. Others have observed growth depressions at these or at lower dietary additions of NO[4, 14]. Maurice *et al.* [4] has ascribed the observed depression in broiler performance on NO diets to a phosphorus (P) deficiency due to high phytic acid content but Hahn et al. [9], using the slope-ratio assay, reported a reasonably high P bioavailability in oat flour and oat bran of 0.60 and 0.42 respectively using tibia ash as the criterion of response.

The object of this paper is to report on experiments on NO with broiler chickens, laying hens and growing ducklings. Descriptions of chemical and biological measurements on different cultivars are also reported. Emphasis is given to Bandicoot a new cultivar released with a yield close to 70% of Echidna, a commercial hulled oat variety[2].

Chemical Composition and Digestibility Measurements

The average chemical composition of Bandicoot is crude protein (CP) = 14.3% (n=45, range 9.8 – 18.3) and oil = 9.9% (n=20, range 7.4 – 11.6). One sample analysed for phosphorus (P) contained 0.41%, of this 85% was as phytic acid P. The ß-glucan content of four samples of Bandicoot ranged from 3.0 to 4.5%. Other NO samples examined were up to 5.7%. The crude protein (CP) and fat contents of 6 genotypes of NO and 2 hulled cultivars (G & H) are given in Table 1. Fat digestibility of NO was depressed (P) in chicks (7–20d) compared to adult cockerels, as a consequence ME was also reduced (P) when using a paired 't test'.

Table 1. Protein and fat contents (DM basis), of ME and fat digestibility of different genotypes of naked oats (A-F) and hulled oats (G-H). Measurements were made with cross-bred chicks from 7-20 days and adult cockerels.

Genotype	CP (%)	Fat (%)	Fat dig. (%)		ME (MJ/kg)	
			Chicks	Cockerels	Chicks	Cockerels
A	15.3	8.4	77.4	86.4	15.0	16.0
B	17.0	7.2	69.3	88.7	14.8	15.8
C	14.8	8.1	74.2	89.3	14.8	15.7
D	14.7	9.6	65.5	88.4	14.7	16.2
E	14.1	8.7	77.2	88.3	15.2	15.8
F	15.6	8.4	55.1	80.6	14.8	15.6
G	10.8	6.2	78.5	91.6	12.1	12.8
H	12.8	5.9	86.3	91.5	12.2	12.9

Table 2. The prediction of essential amino acids (%) in naked oats from their dietary crude protein (% DM, X).

Amino acid	Equation	n	R2	RSD
Methionine	0.099 + 0.012 X	28	0.58	0.021
Methionine + cystine	0.372 + 0.024 X	28	0.41	0.059
Lysine	0.155 + 0.033 X	28	0.79	0.037
Threonine	0.079 + 0.030 X	28	0.83	0.029
Tryptophan	0.011 + 0.013 X	6	0.59	0.026
Arginine	0.115 + 0.079 X	28	0.76	0.096
Valine	0.219 + 0.041 X	28	0.61	0.071
Phenylalanine	0.126 + 0.045 X	20	0.83	0.044
Leucine	0.156 + 0.066 X	28	0.81	0.069
Isoleucine	0.173 + 0.030 X	28	0.54	0.136

The concentration of several important amino acids can be predicted reliably from CP in NO (Table 2). These linear relationships are unusual for cereal grains in that several essential amino acids when expressed as a percent of CP usually decrease with increasing CP content[8]. The biological value of oat protein is relatively constant and high because the globulin fraction increases with increasing CP[15].

The effect of age of bird on ME of a balanced diet containing 85% NO with and without the addition (1g/kg) of various feed enzymes and a mixture (cocktail) is given in Table 3.

Table 3. The effect of various feed enzymes and an enzyme cocktail on the ME (MJ/kg DM) of a diet containing 85% NO fed to groups (n=3) of chickens at three different ages and in adult cockerels.

Age	NO	NO + β-glucanase	NO + lipase	NO + phytase	NO + protease	NO + cocktail	LSD (P<0.05)
4-9d	13.9	14.4	14.0	15.0	14.8	14.8	0.40
11-15d	14.1	14.6	14.3	15.0	15.2	15.0	0.40
18-23d	14.5	14.8	14.7	15.2	15.2	15.3	0.29
Adult	14.5	14.6	14.4	15.1	14.7	15.0	0.48

Only lipase failed to increase ME compared to the control diet (NO) at any age. The most consistent response was to phytase and the cocktail which increased ME even in adult birds. Generally, enzyme addition was less effective as birds aged. We have reported previously the improvement in ME with age of bird and addition of ß-glucanase in pelleted diets containing either 71% wheat or NO at 60 and 84%[7]. Fat digestibility of diets shown in Table 3 increased at 4-9d with the addition of all enzymes except lipase, and at 18-23d for phytase, protease and the cocktail. Adult birds did not respond to enzymes as the fat digestibility was very high on all diets (95-98%). Mean values (%,SD) were 75(1.4), 84(1.3), 88(0.6) and 97(0.2) at 4-9d, 11-15d, 18-23d and in adult birds respectively.

Broiler Chicken Growth Experiments
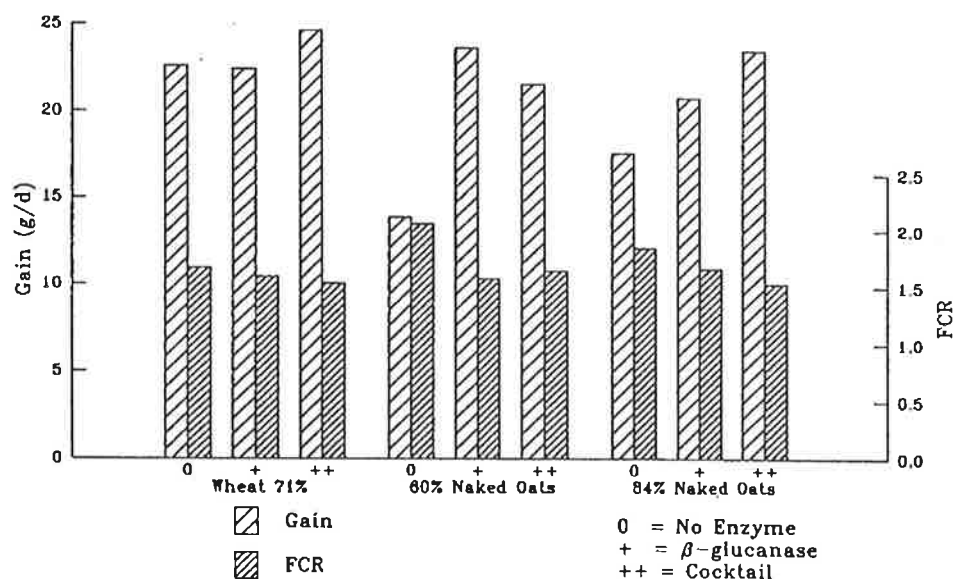
Figure 1. Effects of enzyme (0, + ß-glucanase or ++ enzyme cocktail) in pelleted diets of male broilers grown from 3 to 17d on weight gain and FCR. (LSD, P<0.05 for growth = 2.61, FCR = 0.113).

Farrell et al. [7] showed that for maximum broiler performance it was necessary to pellet the diet and to add a feed enzyme. The results of that experiment are shown in Figure 1. MacLean et al. [12] showed that inclusions of 18-72% NO in the diet of male roaster chickens (4-9 weeks) did not adversely effect performance parameters. Similar studies with hen turkeys to 113d also showed no adverse effects of including NO at levels of up to 66% NO in diets[13].

Duck Growth Experiment

Recently we examined NO in meat-type duckling diets at 10-21d of age. The diets varied from 0 to 73% NO without (-) and with (+) ß-glucanase (1g/kg). Phytase was added to the diet which contained 73% NO. The results are shown in Table 4.

Table 4. Growth rate (g/d), feed intake (g/d), feed conversion ratio (FCR) of growing ducks offered diets without (-) or with ß-glucanase (+) or phytase (++) and the metabolizable energy (ME, MJ/kg) and fat digestibility (%) of the diets.

NO (%)	0	20		40		60		73			LSD
		+	-	+	-	+	-	+	-	++	P<0.05
Gain	56.3	61.2	63.1	57.9	54.6	58.5	45.2	50.9	38.2	56.1	6.87
Feed intake	109	106	111	103	90	94	76	86	67	90	11.8
FCR	1.94	1.73	1.76	1.78	1.65	1.61	1.68	1.69	1.75	1.60	0.178
Fat dig	93.4	90.2	91.3	88.0	84.7	87.3	81.6	86.6	73.1	88.4	8.07
ME	14.8	15.4	15.4	15.2	14.9	15.7	15.1	16.0	15.6	16.2	0.75

Growth rate and feed intake on the diets declined with increasing NO inclusion above 20% (Table 4) and ß-glucanase became increasingly effective on diets with more than 20% NO. Phytase (++) addition to the diet with 73% NO was particularly effective as observed previously (Table 3). The control diet, based on wheat and sorghum, did not give as good a performance as the diet with 20% NO. Overall differences in ME due to enzyme treatment approached significance (P=0.089) whereas fat digestibility was significantly different (P) particularly on the diet with 73% NO (Table 4).

Layer Experiments

Previously we showed that laying hens (30-49 weeks) could tolerate up to 50% of NO in the diet, beyond this egg production and egg mass declined but at a reduced rate if the diet was pelleted[7]. It was hypothesised that the amino acid availability in NO may be reduced even though total dietary amino acids may be adequate for maximum performance. In a very recent experiment we examined the addition of a feed phytase (1g/kg) and 3% fish meal in one diet (Table 5). The experiment with SIRO-CB hens ran for 26 to 36 weeks of age.

Production was depressed on diets with 75% NO compared to the control birds; phytase had no beneficial effects except for feed efficiency. NO at 52% of the diet gave similar results to those on the commercial 17% CP control diet. When 3% fish meal replaced NO in the 75% NO diet egg production was increased (P) but only on the diet without enzyme.

Table 5. Performance of layers on diets with different amounts of NO with (+) or without (-) enzyme and 3% fish meal (FM).

	Control	53% NO	75% NO		72% NO + 3% FM		LSD
			+	-	+	-	(P<0.05)
Feed (g/d)	136	117	110	109	115	109	3.7
Egg prod (%)	89.4	90.5	86.1	84.8	87.1	89.3	2.15
Egg wt (g)	59.6	58.5	57.3	57.9	60.1	57.7	1.76
Egg mass (g/d)	53.7	53.6	50.9	50.5	52.9	51.4	1.06
FCR (g/d)	2.56	2.24	2.18	2.27	2.15	2.21	0.077

Egg weight and egg mass were higher (P) on the diet with enzyme than without and similar to that on the commercial diet.

We analysed the fatty acid content of egg yolk from 5-6 hens (Table 6) on either a control (commercial) diet or choice-fed NO A pelleted protein concentrate of high (37.0%) or low (29.1%) crude protein with minerals and vitamins was offered with NO. The consumption of NO was 69-75% of the total daily intake.

Table 6. The fatty acid content (% total) of egg yolk of hens selecting from NO and a high or low protein pelleted concentrate or on a commercial diet.

Fatty acid	Commercial diet (n=6)	Low protein (n=5)	High protein(1) (n=6)	High protein(2) (n=5)
16:0	26.0	24.4	25.2	24.8
16:1 n-7	3.2	1.6	2.2	2.0
18:1 n-9	44.5	43.6	43.4	43.7
18:2 n-6	10.7	15.7	14.1	15.0
Total saturates	34.9	32.8	34.0	33.2
monounsaturates	51.1	47.7.	48.1	48.3
n-9	45.3	44.5	44.1	44.6
n-7	5.5	3.0	3.8	3.7
n-6	13.3	19.0	17.5	18.2
n-3	0.8	0.5	0.5	0.5
n-6+n-3	14.1	19.6	18.0	18.6

The difference between high protein 1 and 2 was that hens in the former group were about 5 weeks older than the latter. The major difference between eggs from hens on the NO diets and the wheat-based control diet was the higher contents of linoleic acid (18:2, n-6) in eggs from hens on NO diets and the lower content of palmitoleic acid (16:1, n-7). Total monounsaturated fats was higher in the control eggs. These changes are similar to those observed by Aimonen and Uusi-rauva[1] who fed laying hens different dietary amounts of hulled oats.

Conclusions

The results obtained so far indicate the NO can be used in poultry diets up to 50% without adversely effecting egg production or broiler growth. Although the addition of ß-glucanase or an enzyme cocktail overcame the adverse effects of a high inclusion (84%) of NO in broiler rations (Fig. 1), the duckling experiment showed an adverse effect of inclusions of NO to 73% (Table 4). This was not overcome completely with a ß-glucanase or phytase addition. Initially it was thought that pelleting was necessary for NO diets for layers. However a later experiment suggested that this was not the case[7]. The lipid in NO is not fully available to broilers and ducklings (Tables 1 and 4), consequently ME of the diet is reduced. Because NO is rich in oil the availability of ME would be expected to be high. As a consequence feed conversion ratio (FCR) would be lower than on commercial diets as was observed here in most experiments.

Despite the attractive amino acid profile of NO (Table 2), and a high ME (Table 1), the results of the layer experiment (Table 5) indicated that the addition of 3% fish meal had a beneficial effect on an egg production and egg weight (+ enzyme). This suggests that amino acid availability of NO may not be as high as expected.

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Status of Naked Oat Breeding and Commercialization in the USA

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Summary

The most immediate role for naked oats in the USA will be use as an alternate, special purpose crop that will provide the farmer with "home grown" feed that, compared to other feed grains, is high in protein and total digestible nutrients (TDN). The TDN yield per hectare of naked oats will be low relative to several alternate crops in most areas of the USA, however, and acceptance will depend on the relative economics of producing a greater amount of TDN with an alternate crop and then purchasing supplemental protein. The role of oats in crop rotations, as a source of bedding for livestock, and various other special attributes also will be considerations.

Introduction

There has been minimal effort to develop naked-seeded oats, *Avena nuda* L., in the USA. According to Coffman[1], only three cultivars, Fowlds, Nakota, and James (all from South Dakota), were released in the USA from 1921 to 1950. These cultivars were not widely grown becauses of undesirable characteristics such as disease susceptibility, weak straw, low yield (actual or perceived), hairy groats, and groat handling and storage problems. Pennuda is the only naked oat cultivar released in the USA since 1950[4], and it is best adapted in the Northeastern USA. The improved lodging resistance, yield, and groat characteristics of Pennuda and several modern Canadian cultivars have stimulated widespread interest in the potential of naked-seeded oats as a special purpose crop, and this has caused an increase in breeding and testing research with naked oats in the USA. The North Dakota Agric. Exp. Stn. is increasing ND862915 for possible release to seed growers in 1993, and other cultivar releases are likely during the next few years.

We recently sent a questionaire about naked oats to breeders in various states to determine (i) the extent and status of their breeding and testing efforts, (ii) their breeding objectives, (iii) probable crop potential, (iv) hectarage and commercial useage, and (v) probable grower acceptance problems. Based on breeder responses and the insignificant production and utilization of naked oats to date, aggressive research and extention work must still be done to (i) develop an array of naked oat cultivars adapted to different areas of the USA and designed to fill unique niches for the grower and for industry, (ii) develop guidelines to help farmers economically produce and feed naked oats, and (iii) develop specialty markets and uses for the naked grain. Without these inputs in the future, history is likely to be repeated and naked oats will again become a curiosity in the USA.

Location and Scope of Breeding Programs

The amount of naked oat breeding in the USA undoubtedly is restricted by the low level of funding for oat improvement in general. One breeder made the significant point that he finds it difficult to justify redirection of funds to naked oats because covered-seeded oats are grown on the entire hectarage in his state. Regardless, breeders in 16 of 21 states are expending some effort towards improvement of naked oats, but most programs are in preliminary stages. The amount of work with naked oats is less that 5% of the total oat improvement program in five states, 10 to 30% in nine states, and more than 75% in private programs in two states. In one of the private programs (in Washington state), research is primarily to induce useful mutations in lines from other programs. The other private program,

at Marshall Farm in Pennsylvania (supported in part by The Quaker Oats Company), has numerous naked oat lines in various stages of testing and preliminary seed increase. At present, public programs with advanced naked spring oat lines are located in Idaho (USDA-ARS), Illinois, North Dakota, and Ohio.

Lines from the first three programs currently are being tested in a cooperative test described below. Several naked winter oat lines, tracing to the discontinued Coker Pedigreed Seed Company winter oat breeding program, currently are in advanced tests in Florida and Louisiana.

As expected, breeder's objectives are to develop locally adapted naked oat cultivars with improvement of the traits that are most likely to cause problems for growers or commercial users of the grain. The major breeding goals cited in response to our survey were higher yield, improved disease resistance, reduced plant height and improved lodging resistance, resistance to shattering, stability of the naked trait, and the development of groats with high test weight, high protein, high oil, and low levels of trichomes. Naked parents in use in the USA are primarily from the Agric. Canada program at Ottawa, Ontario, the USDA-ARS program at The Pennsylvania Agric. Exp. Stn. (the naked oat work has been discontinued), the Welsh Plant Breeding Stn., Wales, UK, the discontinued Coker program, and a few germplasms in the USDA-ARS Oat Collection (from France, China, and a few other countries). In addition to intercrosses among naked-seeded genotypes, USA breeders are actively crossing those germplasms to locally adapted covered-seeded cultivars and lines that have good disease resistance and other desirable performance characteristics. This is a logical approach to development of adapted naked oat cultivars, but it may prove difficult to combine genetically complex traits from the covered-seeded parents with satisfactory expression of the naked-seeded trait and good groat characteristics. Concurrent with working to develop new populations, several breeders are selecting and testing lines from the naked oat composite populations released by the USDA-ARS and The Pennsylvania Agric. Stn.[2,3,4]. These composites were developed by combining bulk population seed from numerous crosses between naked and conventional oats of various origins. Prior to release, the component bulk populations were subjected to recurrent cycles of selection for high specific gravity seed weight, via a small gravity grader, to eliminate most of the covered-seeded genotypes. Such composites may be especially useful to breeders who can not justify the time and expense required to develop their own populations.

Cooperative Naked Oat Test

A Cooperative Naked Oat Test (CNOT), initiated by the senior author in 1991 with support from The Quaker Oats Company, now is grown at six USA locations and one Canadian location. Two additional states will start growing the test in 1993. At present, the test is limited to breeders who (i) have experimental lines to enter, or (ii) will grow the test in an area of interest to the cooperators. Cooperators submit new seed for all of their entries each year in order to avoid variation in germination that might occur if growers planted back their seed of repeat entries. Extra work is required, compared to covered oats, because growers are expected to determine the proportion of covered seeds, and if possible, the hull content of grain from each line. Our purpose is to learn more about the performance of current naked oat cultivars and lines in different environments. In addition to the usual performance data, we are especially interested in the determining the stability of expression of the naked-seeded trait and the resultant variation in hull content of the grain. Experiences with the CNOT also will provide us with valuable information about unique problems such as satisfactory stand density, harvesting difficulties, and variation in groat quality components.

There were 20 entries plus three check cultivars (one covered seeded) in the 1991 CNOT (the 1992 test has 30 entries plus three checks). Unfortunately, the growing season was extremely hot and dry during 1991 and yields were atypically low. The average yield over entries and locations was only 2316 kg/ha (including hull components). Average yields at locations ranged from only 1360 kg/ha, under extreme heat and drought stress in Pennsylvania, to 5840 kg/ha under irrigation at Aberdeen, Idaho. The average hull content of thoroughly threshed and cleaned grain at the latter location was only 17 g/kg and the best line had only 1 g/kg. Variation over locations in the proportion of covered seeds was small for most lines and cultivars, but environment greatly influenced the expression of that trait in certain lines. Averaged over locations, the proportion of naked groats for lines

ranged from 86 to 99 per 100. Averaged over four locations where the covered-seeded components were dehulled, groat yields for entries ranged from 928 to 999 g/kg. The amount of covered seed for the most variable line ranged from 1 to 31 per 100.

The latter amount of covered seed is undesirable, but regardless, the groat yield was 928 g/kg after removal of the hulls from the covered seeded component. Groat yield data are more difficult to collect than proportions of naked seeds because of the dehulling required, but they provide a useful prediction of the maximum milling yield.

Commercialization of Naked Oats

There are no data on naked oat hectarage in the USA or on the present commercial useage of the grain. Cash grain markets are not developed and there are no standards for purchase of naked grain. We presently advise farmers not to grow naked oats as a cash grain crop unless they have a buyer who is willing to pay a premium to more than offset the weight loss due to leaving the hulls in the field. In response to my questionaire, commercial production was reported by breeders in only five states, and no data are available on the hectarage. Considering the potential of naked oats as a special purpose crop in widespread states six breeders rated the crop low, 11 rated it moderate, and two rated it high. Several breeders indicated that farmers are interested in growing naked oats to produce a useful "home grown" feed or grain for sale.

Based on the widespread demand for seed of Pennuda, at least a few growers are trying naked oats in several states. Outside of the Northeastern USA, the certified seed orders are primarily for small amounts required to grow a trial crop. To date, demand for foundation and certified seed of Pennuda has exceeded the rather conservative amounts that have been produced. Most seed companies have not produced Pennuda seed for various reasons. In Pennsylvania and New York during 1990 and 1991, only 5 of 16 seed companies grew Pennuda, and most of the hectarage in New York was grown by one company. The combined hectarages of Pennuda for seed production in Pennsylvania and New York were 116, 239, and 185 ha in 1990, 1991, and 1992, respectively. Based on that known seed production, farmers in Pennsylvania and New York probably planted less than 5000 ha of Pennuda during 1992. Unfortunately, Pennuda probably received part of the blame for some of the poor yields under the extremely hot, dry conditions.

There is no significant commercial use of naked oat grain by the feed or food industries in the USA. Large feed manufacturers are not likely to change their established ration formulations to include a naked grain component unless a dependable supply is available and they can project some economic advantage to making the change. The situation is further complicated because some feed companies also have operations to produce the grain and supplement components (e.g. protein) that they currently use in their feed products.

A few of the major processors of oats for food in the USA have shown enough interest in naked oats to do some pilot work with the grain. Again, one major concern is the lack of a dependable supply of naked grain because of the low hectarage. Furthermore, during the recent years of increasing demand for oat food products, particularly oat bran, several companies significantly expanded their facilities for processing covered seeded oat grain, and this included expanded capabilities for dehulling the grain. In view of these expenditures and expanded capabilities, one can understand why oat food processors are not rushing out to search for grain of a crop that is only grown on a small hectarage. Perhaps the first significant use of naked oat grain will be in new products that can be produced only from whole oat groats (e.g. for malt). In the near future, smaller companies that do not have dehulling machines to facilitate processing covered oat grain for food are more likely to provide a market for grain from naked oats.

The most active market for naked oat grain in the USA apparently is AgriCulver, Inc., a seed company located near Trumansburg, NY. During 1991, the company sold several tons of cleaned Pennuda grain for trial use in livestock feed, bird feed, and pet food. The industry users apparently were pleased with the results, but so far, have not purchased additional grain for use in their products. They evidently are not willing to pay the premium price required to make the crop economically worthwhile for the farmer and for AgriCulver or

similar providers of a market. In 1992, that company grew about 108 ha of Pennuda to produce seed for sale to growers, and contracted an additional 120 ha to produce grain for possible resale to feed or food processors.

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Breeding Naked Oat for Food, Feed and Industrial Purposes in Canada

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Summary

Opportunities exist for naked oat to become a feed, food and industrial oat. Varying quantities of groats can replace corn and soybean meal in pig and poultry diets. The naked groat can substitute for regular dehulled groats in conventional cereal products but the whole grain might be developed as a rice substitute for table use. New patented steeping technology permits fractionating the groat into high ß-glucan oat bran and refined oat flour components. The bran can be used conventionally, or as a fat replacer in processed meats or as a source of ß-glucan gum. The flour yields starch for alcohol production for gasohol. Alternatively, the steeping process will produce value added starch, protein and oil for the cosmetics industry.

Introduction

In spite of the significant advances that breeders have made in the release of new improved covered seeded oat, *Avena sativa* L., cultivars, the hectarage devoted to production has declined steadily. Oat has lost its position as a major feed grain although there will likely always be a utility role for it on the farm to utilize marginal soil sites, help establish legumes and provide a source of forage and straw. The downward trend in hectarage has been slowed by strong demands for high quality oat for food processing and for feeding valuable recreational horses. As the numbers of work horses declined, and as corn, soybean and barley cultivars and markets improved, the need for large tonnages of oat also declined over the past 50 years. Oat failed to find new major animal clients and this has downgraded its status to that of a specialty crop.

The oat hull with its high fibre content and low nutritional quality has prevented oat from servicing other major users of feed grains such as the pig and poultry industries. In many countries, including Canada, the combination of soybean meal for protein and corn or barley for energy now serve as major constituents in formulated diets for these animals. It seems ironic that the simple removal of the hull by mechanical or genetic means produces a groat with the metabolizable energy and most of the nutritional qualities of the combined corn-soy diet. This is especially important for geographical areas too cool to grow corn and soybeans. In these areas, feed must be imported at ever increasing cost. As continental and international trade in pork and poultry meat and egg products becomes more competitive, more emphasis will have to be placed on developing locally grown feeds to reduce costs of production. The naked oat has the compositional characteristics and the broad adaptability to assume this role in Canada, and elsewhere, if the crop is managed and promoted successfully. We at the Plant Research Centre (PRC), Agriculture Canada, have a mandate to breed new naked seeded cultivars for eastern Canada. We have also cooperated with animal scientists to evaluate the naked oat as a feed grain. By placing much effort on naked oat, other opportunities have surfaced such as the use of whole oat groats as a rice replacement and the industrialization of naked oat for the gasohol and cosmetic industries. Some of the findings and experiences are described in this paper.

Results and Discussion

Feeding naked oat

Experiments were conducted at the Centre for Food and Animal Research (CFAR) Ottawa, Ontario, and the Research Station, Kentville, Nova Scotia of Agriculture Canada, and the Ridgetown College of Agricultural Technology (RCAT), Ontario Ministry of Agriculture and Food, to determine what level of naked oat (cv. Tibor) can be incorporated into poultry and swine diets. Corn-soybean meal commonly served as the control diet in these trials. Within each experiment, most diets had similar caloric values and some were formulated also to provide equal amounts of lysine.

Producing poultry

(a)   **Broiler chickens.** Early results showed that for starter broiler chickens (0-28 days), fed only 20% naked oat in the diet, growth was depressed and sticky droppings were a problem. In grower broiler chickens (29-48 days) a diet containing 30% naked oat supported high weight gain and acceptable feed conversion[6].

Subsequent experiments showed that growth depression in starter broiler chickens resulted from decreased nutrient availability and feed intake from the presence of ß-glucan in the oat grain[8]. Attempts to improve the naked oat by steam and pelleting processes were unsuccessful. Interaction among ß-glucan, bile salts, and fats is believed to reduce absorption of nutrients, including fat-soluble vitamins, from the intestinal tract. The addition of antibiotic and vitamins A, D_3 and E in a water-miscible form improved the performance of broilers (7-21 days). These additives allowed inclusion of naked oat up to 50% of both starter and grower diets with good results. Broiler meat showed a moderate increase in fat stability as oat level increased.

(b)   **Turkey broilers.** Body weight gains of turkey poults fed starter diets (1-28 days) containing 10, 20 or 30% naked oat between 7 and 28 days of age were similar to those given a corn-wheat-soybean control diet (R.M.G. Hamilton, unpublished data). Supplementing the starter diets with the enzyme -glucanase improved feed conversion although the effect was small.

Broiler turkeys were fed grower (29-63 days) and finisher (64-83 days) diets containing 50% naked oat combined with either barley, corn or wheat. Body weight gains for both periods were lower for birds given the naked oat diets than those fed the corn-wheat-soybean control diet regardless of whether or not the diets contained supplemental methionine. Birds given the naked oat diets were significantly better feed converters during the finisher period than the controls (R.M.G. Hamilton, unpublished data).

Eggs

Naked oat can be included at levels up to 60% in layer diets to replace corn, soybean meal and fat. Yield of egg mass was equal to a corn-soybean control diet up to 60% and was reduced by only 4% at 80% naked oat, when no soybean meal was used[7].

When naked oat was supplemented with feed-grade lysine and methionine or canola meal, to the exclusion of soybean meal, dietary levels of 70 or 80% naked oat supported egg yields equal to the corn-soy control. At the 88% level of naked oat, egg size was significantly increased. This is of benefit to young flocks giving better egg grades and higher monetary returns. With older flocks, larger eggs are not desired and the level of naked oat might have to be reduced after about 50 weeks of age.

The efficiency of conversion of feed to egg material was significantly improved over the corn-soy control at all dietary levels of naked oat, except at 88% without amino acid additions. This is a major plus factor for this feedstuff. Due to lack of carotene pigment in oat compared to corn, yolk colour was reduced as the level of oat increased. If required, yolk colour can be intensified by the addition of marigold meal or carotenoids as is done with wheat and barley diets. No consistent detrimental effects of naked oat were found from tests on shell quality, interior egg quality or from taste panel tests.

Producing swine

Weaner pigs. For weaner pigs, as for starter chickens, daily gain on a 90% naked oat diet was less than with a corn-soy control diet. The feed-to-gain ratio was also improved. Adding an enzyme preparation to reduce viscosity of the gum improved daily gain and feed-to-gain ratio but performance was still below the corn-soy diet[15].

Pork. Research at RCAT shows that, in some respects, naked oat completely replaced corn and soybean meal in grower-finisher diets. The weight gains and feed conversions obtained with up to 97% inclusion of naked oat were as good as those of the corn-soy control[14]. In a comparable experiment at CFAR, the same result was obtained[11] but an even better performance was obtained using a 50% naked oat, 50% corn-soy diet. In this experiment, taste panellists concluded, that the meat of oat-fed pigs was superior in texture, flavour and tenderness to that of pigs fed the corn-soy diet. In a second experiment at CFAR, they found flavour was improved but texture and tenderness were equal in the two diets. In one experiment, weight gain was reduced 7% with a 95% oat diet but the addition of lysine ensured high weight gain and improved feed conversion[12]. Because of the high energy content of naked oat, increasing the dietary oat level produced fatter market hogs with correspondingly less lean meat and higher dressing percentage. When a diet is supplemented with lysine, average daily gain improves, excess fat does not accumulate, and carcass quality is comparable to that obtained with the corn-soy diet.

Naked oat for food

Oat has always enjoyed an excellent reputation as a nutritious and safe food grain and the naked oat appears to follow the same tradition. Quaker Oats of Canada and the USA have concluded from experiments conducted with Agriculture Canada that naked oat (cv. Tibor) can be used to make all of the products the company normally makes from the groats of dehulled cultivars. Adjustments had to be made to process the large seeded naked oat but there did not appear to be a difference in basic groat quality. Quaker stated that they would not initiate a program to encourage naked oat production but if large quantities of naked oat became available because of the interest of other clients, such as the feed industry, they were prepared to use them on a regular basis.

Naked oat, like dehulled oat, will likely find greatest use in breakfast cereals but, as time progresses, ever increasing amounts could be consumed at other meals. Oat is known primarily for its nutritional value but oat bran has some well defined functional values. Its beneficial effects in the diets of hypercholesterolemic and diabetic (Type II) patients are well known but the use of oat bran as a fat replacer in hamburger and processed meats is in its infancy. Considering the size of these meat industries, and considering the importance of reducing fat intake, large tonnages of oat bran may be required. Naked oat may not only share in this use but could, at least in Canada, be a preferred source of oat bran as a result of the high quality oat bran produced from the steeping process discussed later.

Canada imports approximately $60M of rice each year and we at PRC have wondered if at least a portion of this grain could be replaced in processed food with specially prepared whole oat groats. PRC entered into cooperative experiments with Ms. V. McTaggart, Food Advisory Division, Agriculture Canada. The experiments were designed to evaluate cooking qualities and recipe formulation of naked oat (cv. Tibor). The results (V. McTaggart, unpublished data) were encouraging but not an instant success. The general conclusion of taste panellists was that cooked groats had a desirable nutty flavour and were superior to rice but the grain texture was more chewy than rice. Some panellists objected to this texture but others found it desirable. Of major concern was the fact that it took 55 minutes to cook by boiling which was too long for busy homemakers. The project fell dormant for several years but has since been revived because of the interest of a member of the food processing industry. UFL Foods, Mississauga, Ontario has undertaken a project, with partial funding by the Ontario Ministry of Agriculture and Food, to develop the technology and recipes for marketing whole groats as a new class of food products. Already we have learned that oat groats can be instantized so they can be cooked in 15 minutes. One of PRC's experimental oat strains (NO753-2) is more tender after cooking than the cultivar Tibor. This project may have a reasonable chance of success because consumers are learning the real value of oat products and if tasty, inexpensive side dishes can be made from oat this may increase the demand for naked oat.

Oat for industrial uses

Presently we tend to think of oat as a feed grain with some food uses. This is in contrast to how we view corn which is used for feed, food and industrial purposes. Industrial uses raise the value of the crop because many of the refined products are high priced. More importantly they are consumed by clients that can afford to pay for them. A major effort is being made in Canada to industrialize the oat crop to produce alcohol for gasohol production; oat bran for the food processing industry; starch, protein, oil and wax products for the cosmetics industry and other chemicals for the pharmaceutical industry. This development became possible as a result of some unrelated research that took place in 1978 at PRC. Burrows was trying to induce secondary dormancy into a covered seeded dormoat strain using a hot water steep. After steeping the embryos failed to germinate but the endosperm liquified. The grain essentially reverted to the milk stage. Burrows was able to obtain the same result using the covered seeded variety Hinoat and several naked oat strains. Apparently, during steeping endogenous cell wall degrading enzymes in the endosperm cells were activated and slowly broke down the cell walls. However, the enzymes did not hydrolyse the subaleurone cell walls that are thickened with ß-glucan. Dr. G. Fulcher, PRC cereal quality specialist, now at the University of Minnesota, determined that the starch and protein bodies were not attacked during steeping. The process inhibited the synthesis of amylases and proteases by the aleurone cells. After washing and drying, the bran contained approximately 15-17% ß-glucan. The endosperm could be dried to produce a refined oat flour. Dr. David Paton, food processing specialist, CFAR, joined the project and his contribution was to scale up and refine the process to produce products for commercial evaluation. Dr. Paton who is now working for Agriculture Canada at the Protein, Starch and Oilseed Plant at Saskatoon, Saskatchewan, was mainly responsible for patenting the process[1] in a number of countries. Later when it was found that flour and bran produced by this process went rancid with time. Dr. Bill Collins, chemist at CFAR, and D. Paton introduced an alcohol treatment step into the basic process which solved the rancidity problem as well as reduced microbial contamination in the bran and flour.

The choice of alcohol to deal with the rancidity problem was fortunate because it led Paton to Mohawk Oil Co., Calgary, Alberta, to inquire about a source of alcohol for the process. Mohawk became interested in the process to make alcohol from the oat starch because the high quality oat bran could help pay for processing. This oat bran also provides an excellent starting material from which to extract pure ß-glucan gum. Mohawk leased the steeping technology in May, 1992, to make oat bran and alcohol.

The cosmetic industry has also taken an active interest in oat components. Oat starch is fine grained and makes excellent face powders. The fine grains accept pigment well after some secondary processing, the market is large and the dollar values of facial and body powders are high. Talc which has been used in facial and body powders is rapidly falling out of favour because it is mined near asbestos which has known health risks. Oat starch is a safe alternative. The industry is also interested in oat protein to make products such as lotions and shampoos. Oat oil and waxes are also of value in skin care products. The cosmetics industry is huge, even in an economic recession, and it has come to my attention that companies in Europe and the USA are already building facilities to process oat for cosmetic purposes. In any fractionating process it is important that as many components as possible have functional and economic value.

The steeping process appears to work most effectively with naked oat rather than with groats derived from dehulling conventional covered seeded cultivars. Dehulling causes a high percentage of broken or cracked kernels which results in problems in regulating steeping times and microbial contamination to obtain uniform end products of food grade. To overcome this problem, the dehulled grain must first be sized by sieving and losses of starting material as high as 50% have been obtained. Damage to the grain before steeping may make it necessary to shorten storage times because of the development of rancidity. Clearly the process will work best if Mohawk is able to obtain naked oat of good quality on a regular basis.

Cultivars

Seed of six naked oat cultivars is available in Canada. Terra[13] and AC-Belmont (D. Brown, unpublished data) were bred at the Winnipeg Research Station, Agriculture Canada for

western Canada and Tibor[2], AC-Hill[3], AC-Lotta[4], and AC-Percy[5] were bred at PRC for eastern Canada. PRC has a very large naked oat breeding program and several new cultivars will likely be released within the next 2-4 years. They represent improvements in yield potential, lodging resistance, disease resistance, lower percentage of covered seeds in threshed grain samples, reduced groat hairiness, and grain quality including protein, oil and ß-glucan contents. A backcrossing program is in progress to convert 20 covered seeded cultivars and advanced strains that are recommended in various regions of Canada to naked cultivars. This was done to ensure that if companies or individuals in any region required a naked oat cultivar they would be able to use a cultivar adapted to their area. It was considered unrealistic to expect that a few cultivars bred at Ottawa or Winnipeg could serve clients in a country as large as Canada.

From these results it is clear that the breeding specifications on grain quality of new naked oat cultivars will have to meet the requirements of users more closely. Groats that are to be used to feed pigs and poultry should be as low in ß-glucan as possible and high enough in protein and oil to meet diet requirements. Breeding for low ß-glucan is possible and values as low as 2.3% have been achieved but Cave[10] calculated that a value of 1.6% would be acceptable for broiler chickens. Cultivars for the food market probably should be as high in ß-glucan as possible, average to high in protein and average to low in oils for caloric reasons. Again genetic stocks rich in ß-glucan are available and present information at PRC indicates that ß-glucan level is not related to grain yield potential. Writing specifications for an industrial oat is more uncertain because the starch, protein, ß-glucan and oil components all have substantial but different monetary values. It probably is a good strategy to first breed two types of new cultivars that are either very low or very high in ß-glucan. The protein content should be as high as possible in both types without sacrificing yield potential and the oil content should be average for the species. As commercial specifications become more refined, breeding objectives will change. Breeders should be aware that the creation of a roster of new naked oat cultivars designed for specific end uses could lead to a requirement for kernel distinguishability, contract growing or the use of affidavits for marketing purposes.

The future of naked oat is showing great promise because more market uses have been identified. The addition of an industrial use for oat could be the major stimulus needed to increase oat hectarage.

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Variation in the Nutritive Value of Oat Grain for Ruminants, and its Measurement by Near Infrared Spectroscopy

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Summary

The protein content of oat grain was determined in 2176 samples submitted to a feed testing service, mainly from Victoria, encompassing nine seasons and many varieties. Protein varied from 4.7 to 16.0%, and the mean was 8.9%, with all varieties exhibiting a wide range. Mortlock was higher in protein (P<0.05) than the other varieties, and Echidna was no different to Swan (P>0.05). There was no consistent seasonal effect on protein for the five major varieties studied. Samples originating in southern Victoria were either the same or higher in protein content compared with those from northern Victoria. Protein in oats was accurately and precisely determined by the rapid and non-destructive technique of near infrared spectroscopy, with a standard error of 0.38%. NIR prediction of digestibility of oats, based either on *in vivo* data or pepsin-cellulase dry matter disappearance, is currently under investigation.

Introduction

Unlike wheat, approximately 80% of the oats produced in Victoria is held on farms for stockfeed, especially during times of seasonal feed shortage or drought[1]. Oats contains the lowest starch and highest fibre of any cereal grain, due to the proportion of hulls, which can vary from 20% to 50%[2]. Hence oats is the safest and most popular cereal grain to feed to grazing ruminants, particularly as a supplement during late summer and autumn in southern Australia, when pasture is usually low in both quality and quantity.

However a major limitation of oats can be its low protein content. In Europe, oats may vary in protein from 6% to 17%, with the average being 12%[2], but it has long been recognised that the protein content of Australian oats is generally much lower[3,4].

In ruminants the microbial population of the rumen derives most of its nitrogen requirement from the diet of the animal. When dietary protein is too low, the rumen micro-organisms will decrease in numbers and rumen fermentation will be reduced. This will adversely affect digestion in the host animal and cause it to suffer from undernutrition. When oat grain with a protein content at the lower end of the range in Australian oats is fed as a supplement to dry pasture, there will be insufficient protein in the total diet for rumen and animal maintenance.

The detrimental effect of oats with a low protein content was demonstrated in two ways by work at Hamilton which compared oats containing low (7%) and high (12%) protein (Foot, unpublished data). Rumen fermentation in weaner sheep was found to positively respond to non-protein nitrogen added to oats containing low protein, but there was no such response with oats containing high protein, as protein intake was already adequate. In a second experiment, weight losses in weaner sheep grazing dry pasture were greater and more frequent when they were fed the oats containing low protein. However, when the pasture contained more than 5% "green pick", which is high in protein, no difference in response to the two supplements was observed.

During prolonged dry periods, common in northern Victoria and in most other States, green pick is not available as a protein source. The amount of protein in the supplement then becomes critical for the well-being of stock grazing mature pasture. Consequently, a knowledge of the protein content of oat grain is vital before planning its use in such a situation.

Laboratory measurement of protein has almost always been accomplished by the time-honoured but slow and hazardous Kjeldahl method. However, the increased demand for rapid grain and feed analysis in recent years has necessitated a different approach. The non-destructive, instrumental technique of near infrared reflectance spectroscopy (NIR) offers a convenient means of meeting this demand.

Since the first commercial NIR instruments were introduced to measure oil, protein and moisture in grain[5], the technique has gained wide acceptance for many analytical applications in agriculture and industry. Protein analysis of wheat is now almost universally conducted using NIR, but there have been fewer reports of its application to oats. Some of these have been confined to dehulled oats (groats)[6,7], no doubt due to the difficulty of obtaining homogeneous ground samples of whole oats, which are notoriously difficult to grind because of their relatively high husk and oil content. Williams[8] and Biston[9] measured protein in ground whole oats, but found that standard errors were considerably higher than for wheat or dehulled oats.

Estimation of dry matter digestibility (DMD), and hence metabolisable energy (ME), of oat grain in the laboratory is fraught with difficulty. Firstly, the narrow range of DMD for oats compared to forages (60 to 82%)[10] reduces the accuracy of any *in vivo/in vitro* relationship. Secondly, *in vivo* measurements are subject to errors due to variation in intake between animals on the same diet, particularly if grain is fed as the sole ration[11]. DMD also varies with the level of feeding[12] and the physiological status of the animals[13]. Finally, although it is widely accepted that ME is best calculated directly from DMD, there is evidence that the assumed ratio of ME to digestible energy (DE) (0.81) is inappropriate for oats, and may be as high as 0.88[12].

The DMD of feedstuffs can be estimated from chemical composition, such as nitrogen and acid detergent fibre[14]. For forages, the most accurate and successful laboratory estimate of DMD has been the two-stage *in vitro* procedure or, more conveniently, the pepsin-cellulase technique[15]. However, the technique needs to be standardised with samples of known *in vivo* DMD as similar as possible to those being tested. In the case of cereal grains, starch must also be removed either using amylase or a high temperature digestion[16].

Two approaches can be used to estimate DMD using NIR. Either a direct calibration can be derived for *in vivo* DMD, or one which utilises *in vivo* values estimated from a linear regression against pepsin-cellulase dry matter disappearance (PCDMD). The advantage of the former is that the laboratory *in vitro* technique is completely bypassed, thus eliminating a number of errors. However, a successful NIR calibration requires a relatively large sample population, with accurate reference data measured using consistent methods and preferably at the same location by the same personnel. It is much more difficult to obtain this for *in vivo* than for PCDMD values.

The objective of this study was to assess the variation in protein content of oat grain across varieties, seasons and locations, and to derive and implement a robust NIR calibration for the determination of protein in oats, covering large and diverse sample populations. Some preliminary results on the estimation of DMD in oats are also presented, using both the pepsin-cellulase technique and direct NIR calibration.

Materials and Methods

The study involved a total of 2176 samples of oat grain, either collected during a Victorian survey conducted in 1983/84 and 1984/85, or submitted to a feed testing service over the following seven seasons. Victoria accounted for 92% of all samples; the remainder originated mainly from South Australia and Western Australia. Many different varieties were represented, and the distribution of varieties among seasons is shown in Table 1.

Prior to 1987, oats samples were dried at $65^{\circ}C$ overnight and ground in a Makla hammermill using an 0.5 mm screen. Since 1987, all samples have been ground in a Tecator Cyclotec mill containing a 1 mm screen, without prior drying. Conventional analysis for crude protein (CP) was conducted either using a micro-Kjeldahl digestion procedure followed by automated colorimetric determination of ammonia, or else by the conventional Kjeldahl procedure, but using a Tecator Kjeltec system. CP was expressed as nitrogen x 5.83, which is

the factor recommended for oats[17] instead of the usual 6.25, as the latter is known to overestimate the total CP content of cereals and oilseeds due to different plant proteins containing different levels of nitrogen[18].

Table 1.   Distribution of oats samples tested, 1983-1992

Variety	83/84	84/85	85/86	86/87	Season 87/88	88/89	89/90	90/91	91/92	TOTAL
Avon	11	7	-	-	-	-	1	-	-	19
Bulban	30	67	12	6	3	5	8	4	4	139
Bundalong	-	-	-	3	12	2	4	4	3	28
Cooba	2	5	-	-	3	4	2	1	-	17
Coolabah	36	43	2	10	3	14	10	4	5	127
Dalyup	-	-	-	-	-	-	1	6	42	49
Dolphin	-	5	5	9	3	7	8	3	4	44
Echidna	-	4	14	57	81	143	253	144	127	823
Esk	-	5	1	2	2	1	5	3	4	23
Kalgan	-	-	-	-	-	-	1	4	5	10
Marloo	-	-	-	-	-	3	4	3	2	12
Mortlock	-	1	-	3	19	22	38	22	26	131
Nile	-	-	-	-	-	1	8	8	6	23
Saia	4	6	-	-	1	-	1	-	-	12
Swan	67	83	7	14	21	16	16	4	10	238
Wallaroo	-	-	-	-	-	-	2	6	2	10
West	8	25	-	1	4	-	1	1	-	40
Winjardie	-	-	-	-	-	2	3	2	4	11
Other	8	6	3	1	3	-	1	2	4	28
Unknown	-	-	9	19	60	76	106	66	56	392
TOTAL	166	257	53	125	215	296	473	287	304	2176

Means and standard deviations were calculated for CP across all varieties for each season, and across all seasons for each variety. Differences between means were assessed for significance using Student's *t* test. For Victorian samples of Echidna and Swan varieties, comparisons of CP were also made between samples originating from either north or south of the Great Dividing Range.

An NIR calibration for CP was obtained using 118 oats samples, which were selected on the basis of their NIR spectra as a representative subset of a much larger population. NIR spectra were collected on each sample using an NIRSystems model 6250 scanning monochromator. Spectra consisted of 700 absorbance values, measured as log 1/R (where R = reflectance), between the wavelengths of 1100 and 2498 nm, at 2 nm intervals. The calibration equation was developed using modified partial least squares (PLS) regression, and statistically evaluated on a separate population of 142 samples. All data collection and processing was conducted using Infrasoft International (ISI)[1] software.

A linear regression was derived between *in vivo* DMD and PCDMD for a set of 21 grains comprising 8 oats, 2 barley, 4 triticale, 2 wheat, 3 peas, 1 lupins and 1 faba beans. The *in vivo* data were obtained from a number of different digestibility trials carried out with wether sheep at Hamilton between 1983 and 1992. PCDMD was measured using a modified version of the method of Clarke *et al.* [19], incorporating a high temperature digestion to remove starch[16].

An NIR calibration was obtained for *in vivo* DMD, using 80 samples of cereal grains (35 oats, 20 barley, 20 wheat, 5 triticale). These samples represented a variety of trials, locations, experimental conditions and times. Similar procedures were followed as for the CP calibration, except that it was not possible to test the chosen equation on an independent sample population.

Results and Discussion

Table 1 shows the rise and fall in popularity of certain varieties over the nine seasons studied, assuming the number of samples received relates to the prevalence of the varieties grown. During the 1983/84 and 1984/85 survey, Swan, Coolabah and Bulban were the most common varieties, but declined considerably in numbers over the following seasons. By contrast, the high-yielding variety Echidna, released in 1984, has become by far the most frequent one tested, with Dalyup and Mortlock also increasing in numbers.

The mean, standard deviation and range of CP for each variety of oats across all nine seasons are shown in Table 2.

The CP content of all oats tested varied from 4.7 to 16.0%, and the mean was 8.9%, with all varieties exhibiting a wide range. With the exception of Saia, which is in fact a different species (*Avena strigosa*), the mean CP for all varieties varied between 8.2 and 10.8%. Echidna, commonly considered by farmers to be a low protein oat, was statistically no different ($P>0.05$) to Swan, but Mortlock was significantly higher ($P<0.05$) in CP than the other major varieties. Overall, mean CP was 15% lower than that reported by Barr[4] in a study comprising 12 oat varieties in 69 trials conducted in South Australia over nine years.

Seasonal differences in CP across all varieties studied are shown in Table 3, which indicates that the CP content of oats samples from the 1986/87, 1989/90 and 1990/91 seasons was significantly lower ($P<0.05$) than in all other years, and that in the 1984/85, 1985/86 and 1991/92 seasons CP was significantly higher ($P<0.05$) than in all other seasons except 1983/84.

Seasonal differences in CP between the five major varieties are shown in Figure 1. There was no consistent seasonal effect on CP for the five major oat varieties. For Coolabah and Mortlock, there were no significant differences in CP ($P>0.05$) between seasons. The Bulban samples in 1986/87 were significantly lower ($P<0.05$) in CP than in all other seasons, and both the Swan and Echidna samples in 1991/92 were significantly higher ($P<0.05$) in CP than in all other seasons. The Echidna samples in 1986/87, 1989/90 and 1990/91 were significantly lower ($P<0.05$) in CP than for the other seasons.

The effect of sample origin (either north or south of the Great Dividing Range) on CP for Victorian samples of either Echidna or Swan, in three and two seasons respectively, is shown in Table 4. In general, mean CP content was higher in southern Victoria, but significantly so ($P<0.05$) only in the 1991/92 season for Echidna and in the 1983/84 season for Swan. One possible explanation is that oat crops in southern Victoria are more commonly sown in paddocks previously under pasture, and soil nitrogen could be higher than in northern Victoria where crop rotation is more common.

The effects of season, variety and sample origin on CP content of oats in this study need to be interpreted with considerable caution. Clearly, replicated experiments across different environments and seasons are the only definitive way to reach valid conclusions. In this study, the population was determined solely by voluntary submission of samples by farmers or advisors, with widely varying numbers from different areas and seasons, which could cause biased results. Nevertheless, the large number of samples gives a useful indication of the range and approximate trends in CP of farm oats in southern Australia.

Table 2. Crude protein (nitrogen x 5.83) content, expressed as per cent of dry matter of oat grain varieties tested, 1983-1992. Means for the five major varieties followed by different letters differ significantly (P<0.05)

Variety	No. of samples	Mean	Standard deviation	Range
Echidna	823	8.4 a	1.27	5.2 - 11.9
Swan	238	8.6 a	1.39	4.8 - 12.6
Bulban	139	9.5 b	1.63	6.5 - 14.8
Mortlock	131	10.8 c	1.27	7.6 - 14.0
Coolabah	127	9.7 b	1.54	4.7 - 14.1
Dalyup	49	10.0	1.22	7.8 - 13.2
Dolphin	44	9.5	1.58	6.4 - 13.8
West	40	9.2	1.65	5.0 - 12.3
Bundalong	28	8.2	0.92	6.7 - 9.9
Esk	23	10.0	1.13	7.2 - 12.0
Nile	23	9.5	1.32	7.5 - 12.4
Avon	19	8.7	1.36	6.0 - 11.0
Cooba	17	10.0	1.62	6.3 - 12.7
Marloo	12	10.1	1.55	7.5 - 12.7
Winjardie	11	8.9	1.01	7.4 - 10.7
Kalgan	10	9.4	1.11	8.0 - 11.8
Wallaroo	10	10.2	2.23	7.5 - 13.1
Other varieties	28	10.2	1.54	7.2 - 12.5
Unknown	392	8.6	1.54	5.0 - 13.6
Saia *	12	13.7	1.04	12.3 - 16.0

* *Avena strigosa*

Table 3. Seasonal differences in crude protein (nitrogen x 5.83) content, expressed as per cent of dry matter, for all oats samples tested Means followed by different letters differ significantly (P<0.05)

Season	No. of samples	Mean	Standard deviation
83/84	166	9.2 bd	1.73
84/85	257	9.4 cd	1.73
85/86	53	9.6 cd	1.37
86/87	125	8.4 a	1.44
87/88	215	9.1 b	1.58
88/89	296	9.0 b	1.60
89/90	473	8.5 a	1.42
90/91	287	8.4 a	1.53
91/92	304	9.5 c	1.47
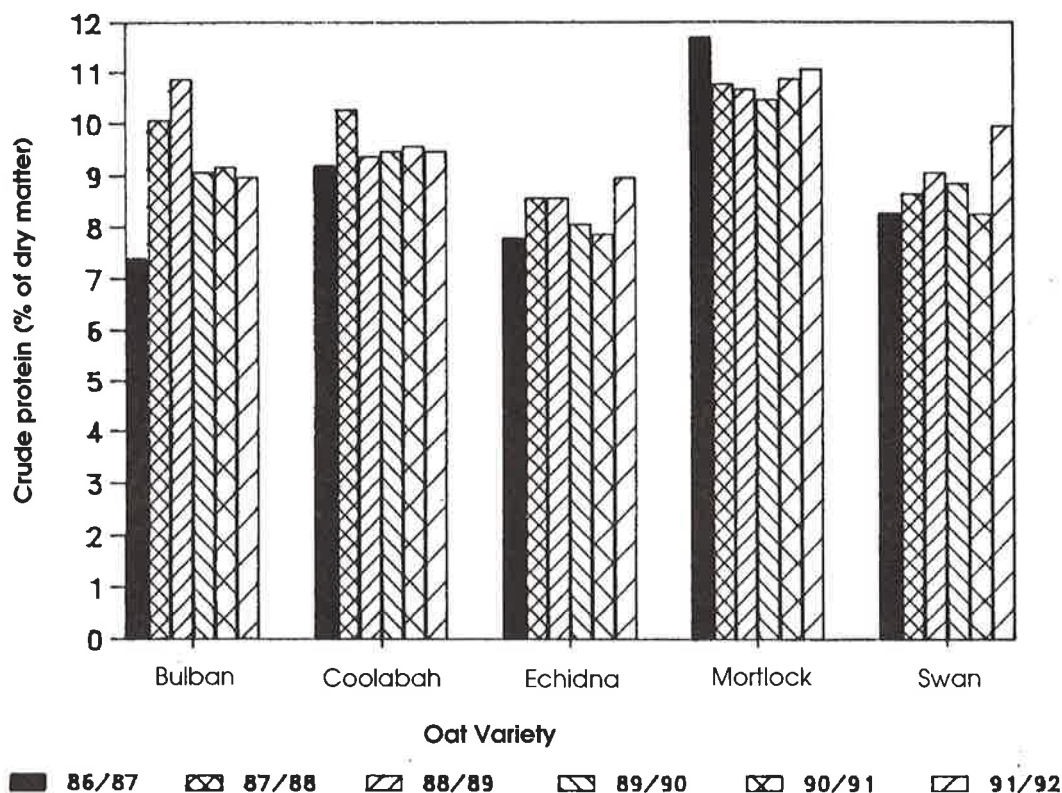
Figure 1   Seasonal differences in crude protein content
of the five major oat varieties studied

Table 4.   Effect of sample origin on crude protein (nitrogen x 5.83) content,
expressed as per cent of dry matter, of Victorian samples of Echidna or Swan oats
N, number of samples; SD, standard deviation
Within rows, means followed by different letters differ significantly (P<0.05)

Season	Variety	Northern Victoria			Southern Victoria		
		N	Mean	SD	N	Mean	SD
83/84	Swan	25	7.8 a	1.64	42	8.7 b	1.10
84/85	Swan	21	8.1 a	1.69	62	8.8 a	1.00
89/90	Echidna	48	7.8 a	1.18	176	8.1 a	1.11
90/91	Echidna	24	7.9 a	1.31	107	7.8 a	1.00
91/92	Echidna	18	8.4 a	1.10	93	9.0 b	1.17

The calibration statistics for the measurement of CP in oat grain by NIR are shown in Table 5. The best PLS equation obtained for CP utilised a multiplicative scatter correction and a (1,10,10) derivative math treatment (order of derivative, wavelength segment in nm over which the derivative is calculated, smooth in nm)[20]. Standard error of cross validation (SECV) in this case refers to the error measured when every fourth sample was set aside for validating the calibration derived using all other samples, such that each sample in turn was used in both calibration and prediction. Standard error of performance (SEP(C)) is the error measured when the final calibration equation was tested on a separate population.

NIR was able to predict CP in oats with a standard error of 0.38%, which compares favourably with published errors of 0.47%[8] or 0.41%[9]. Bias was low, slope was close to 1.0 and the SE/SD ratio was below 0.3, thus conforming to optimum statistical criteria[21].

In vivo DMD (%) was related to PCDMD (%) for the 21 grains by the equation:

DMD   = $12.32 + 0.797$ PCDMD (R^2 0.92, RSD 2.38)

DMD ranged from 66.8 to 92.4% (oats 66.8 to 76.9%, barley 79.0 to 81.2%, wheat and triticale 83.4% to 92.4%, and grain legumes 84.9 to 88.6%). This relationship was at least as accurate as many published equations for estimation of DMD in forages, and compared favourably with those reported by Oddy et al. [10] relating DMD to various chemical components.

Table 5. NIR calibration statistics for per cent crude protein (CP) of oat grain, using modified partial least squares (PLS) regression
SD, standard deviation; R^2, coefficient of determination;
SECV, standard error of cross validation;
SEP(C), standard error of performance, corrected for bias

	Calibration set (n=118)	*Validation set (n=142)*
Mean	9.1	8.5
Range	5.2 - 14.8	5.9 - 13.1
SD	1.86	1.42
R^2	0.95	0.93
SECV	0.41	-
SEP(C)	-	0.38
Bias	-	0.02
Slope	-	0.97

The 80 samples used for NIR calibration of *in vivo* DMD were part of a larger population of 95 grains. Of these, 7 were grain legumes, and were identified by the computer program as spectral outliers and therefore omitted from the calibration. The other 8 samples omitted were oats, also identified as quite different to the remainder, either spectrally or in terms of DMD.

The NIR calibration statistics for *in vivo* DMD in the set of 80 samples were quite encouraging. DMD ranged from 62.3 to 92.4%, with a mean of 80.2% and an SD of 8.1%. The R^2 and SECV values were 0.86 and 3.13 respectively. This level of error is well within the range of that reported for *in vivo* DMD[22], and again compares favourably with the error in estimating DMD from chemical constituents[10]. However, further work is required to validate the equation on an independent population, which will take time due to the effort and resources required to conduct digestibility trials. Improvements in accuracy would also be likely if each trial were conducted under identical conditions.

It is clear that NIR has a useful role in allowing producers a rapid means of monitoring the quality of feed oats, including prior to purchase, in order to ensure that their stock are receiving adequate protein and energy during times of nutritional stress.

Acknowledgements

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Structural Features of Lipid- and Protein-rich Oat Grains

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Summary

Low- and high-lipid oats were studied microscopically in order to document structural and compositional features of mature and developing grains. The adopted methods comprised light microscopy (LM) and scanning and transmission electron microscopy (SEM and TEM). Emphasis was put on aleurone and outer endosperm cells. SEM was useful for differentiating high-lipid grains since they have an oil coverage when cleaved. By toluidine blue staining and LM, it was possible to differentiate lipids, proteins and starch. The lipids were less densely stained in aleurone than in endosperm cells of high-lipid oats. TEM elucidated structural details of lipid and protein localization and storage. The microscopical approach is a valuable complementary tool for determination of quality criteria which are of relevance to the breeder and in industrial application.

Introduction

Like in other cereals, the major component of the oat grain is starch. However, the attention of plant breeders, nutritionists and industrial users has been directed to the protein, lipid and ß-glucan components of the grain. The protein quantity and quality have contributed to the importance of oats as a livestock feed and a cereal breakfast food. The lipids are nutritionally important since they are highly unsaturated and rich in linoleic acid. ß-glucans are considered as an important dietary fibre source and as a potentially valuable industrial hydrocolloid. In addition to the chemical and physical methods used for grain quality evaluation, microscopical and cytochemical approaches may be considered as complementary means to elucidate developmental patterns and to define quality criteria in anatomical, cell structural and cytochemical terms. Certain structural and cytochemical features of the oat grain have been described earlier employing SEM[5], TEM and immunocytochemistry[1,3,4,6], and fluorescence microscopy[2,7]. In this report, we focus on cell structural and cytochemical analyses of lipid and protein accumulation during the development of the oat grain in materials with low and high lipid contents.

Materials and Methods

Low- and high-lipid oats (*Avena sativa* L.), the cultivar "Vital" and the breeding line Sv90689 were used. Their lipid content amounted to 5% and 10%, and the protein content to 10% and 13%, respectively. For SEM analysis, mature grains were cleaved transversely, coated with gold/palladium and studied in a JSM-25S II at an accelerating voltage of 12.5 kV. For LM and TEM, immature grains about 16 days after anthesis were conventionally fixed in glutaraldehyde and osmium tetroxide, chemically dehydrated and embedded in Spurr's resin. Thick sections (1μm) for LM were stained with toluidine blue O and ultrathin sections were stained with uranyl acetate and lead citrate before examination in a Zeiss EM10C.

Results and Discussion

The differences between the low- and high-lipid oat materials studied, as to occurrence, distribution and accumulation of lipids and proteins, will be restricted to observations made on aleurone and outer endosperm cells. Corresponding sites in grains of these materials, documented by SEM, LM, and TEM, are exemplified by Figures 1–6. The endosperm cells of mature grains, as visualized by SEM, disclosed distinct morphological differences between the two oat materials. In low-lipid oats, it was possible to recognize structures such as cell walls, starch grains and intervening storage materials (Figure 1).
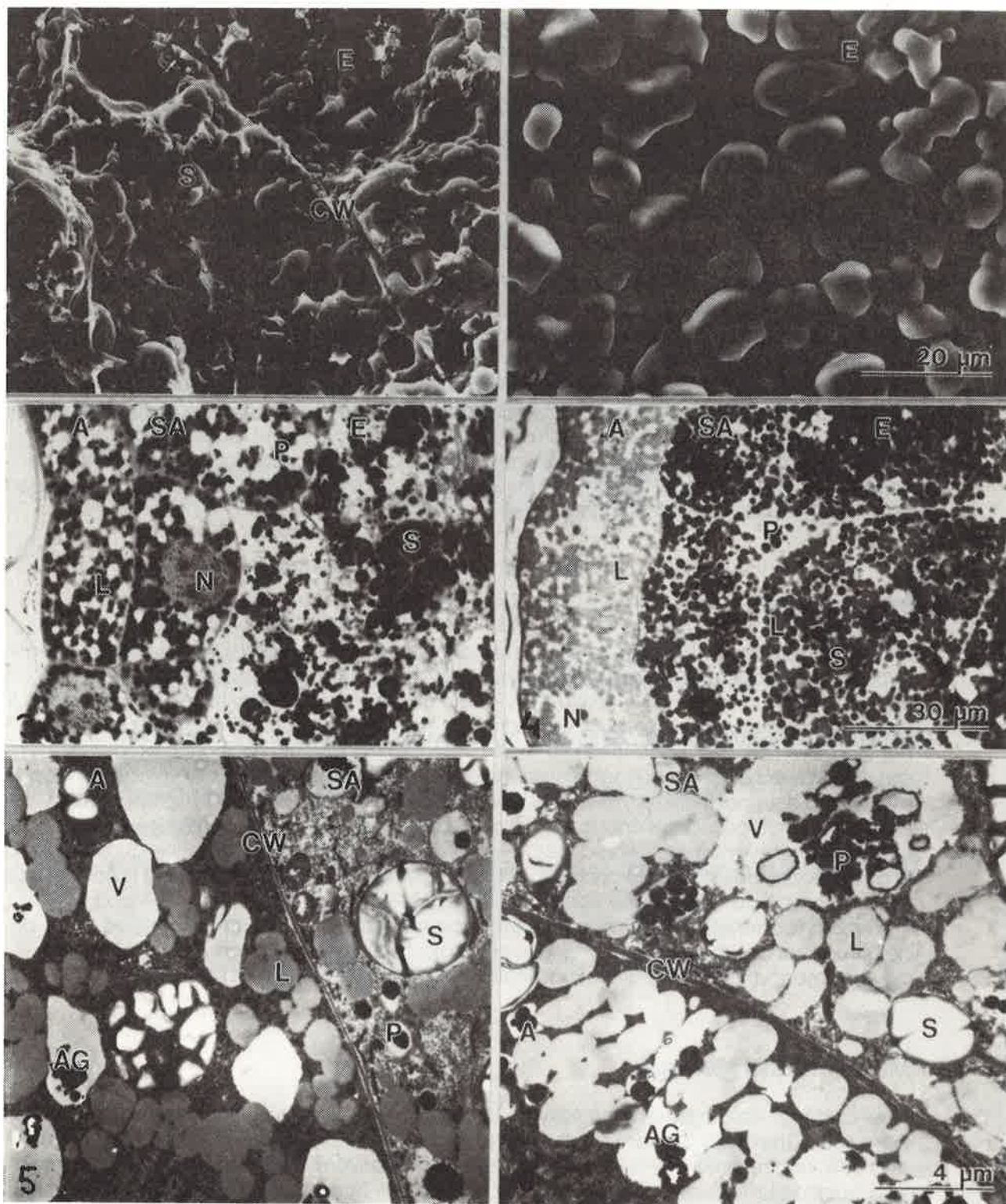
Figures 1-6. Structural features of low-lipid (Figures 1,3,5) and high-lipid (Figures 2,4,6) oat grains, using SEM (Figures 1,2), LM (Figures 2,3), and TEM (Figures 5,6).
A, aleurone; AG, aleurone grain; CW, cell wall;
E, endosperm; L, lipid; N, nucleus;
P, protein; S, starch; SA, subaleurone.

Figures 1,2. Disclosure (Figure 1) and masking (Figure 2) of cellular structures, depending on the level of lipid contents.

Figures 3,4. Low (Figure 3) and high (Figure 4) lipid contents, and a lower staining density of lipids in aleurone cells of high-lipid oats (Figure 4).

Figures 5,6. Ultrastructural features of lipids, proteins, and starch in aleurone and subaleurone layers.

In high-lipid oats, however, it was difficult to resolve cellular or subcellular structural details due to the presence of a confluent oil coverage (Figure 2). In thick sections of resinembedded immature oat grains, it was easy to differentiate lipid, protein, and starch components (Figures 3,4). As expected, lipid vesicles (grey/green colour) were more frequent in the high-lipid oats. The intensity of lipid coloration was lower in the aleurone cells than in the subsequent endosperm cells in high-lipid oats (Figure 4), but this was not the case in low-lipid oats (Figure 3). Protein bodies (blue or reddish blue) were mainly located in vacuoles, and were more abundant in high-lipid oats. The starch granules (purple) occurred mainly in large aggregates. The ultrastructure of these storage components and the differences between low- and high-lipid oats are well elucidated by TEM (Figures 5,6).

The present results indicate that SEM is a suitable method for the screening for highlipid contents. Fluorescence microscopy has been useful for the demonstration of lipids[2,7], but with bright field LM, it has till now been difficult to detect cereal endosperm lipids. The present results, however, show that toluidine blue O is a suitable stain for the differentiation of lipids, proteins and starch. TEM and immunocytochemistry have provided valuable information of protein synthesis and accumulation[1,3,4,6]. Corresponding knowledge regarding lipid synthesis, processing and storage remain to be enriched.

The microscopical approach is an elucidative method complementary to chemical and physical methods used to evaluate and screen for specific quality criteria. The knowledge gained about the cereal grain through microscopy and cytochemistry, and the use of these methods for screening purposes, are of significance for the oat breeder and the industrial user.

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Setting and Achieving Oat Breeding Goals to Meet Specialized and New End Uses

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Summary

The oat crop has many uses: A companion for establishing forage seedings, a source of straw for livestock bedding, and grain for food and feed. Traditionally, the primary use of oat grain has been as a livestock feed, especially for horses and young swine and poultry, but a smaller percentage (10-25%) is used for human food. Naked oats (which is controlled by alleles at one locus) would have higher energy value in livestock feeds than would covered grain, and if the trait is completely expressed, it could eliminate the dehulling portion of the oat milling process.

It is possible to develop oats with a 20.0-21.0% protein in the grain, with 16% and perhaps greater oil contents, and with elevated levels of ß-glucan. Enhancement of any or all of these compositional traits may make them more valuable for human food and perhaps for livestock feed. These characters show a low level of genotype x environment interaction, have heritabilities of 40-60% when a single plant is the selection unit, and are controlled by additive gene action.

Short-term goals for modifying any of the seed traits discussed herein can be accomplished with conventional plant breeding procedures, such as pedigree, single-seed descent, and at times backcrossing with single, three-way, and double crosses used as the sources of recombination. For long-term goals of trait enhancement, phenotypic recurrent selection would be preferred utilizing a gene pool with alleles from many sources.

Introduction

Oats, throughout much of the world, is a multipurpose crop. That is, it has many uses during production and as a product. Examples are (a) as a "companion" or "nurse" crop for the establishment of forages, (b) as a source of straw for bedding for animals, (c) for grain for livestock feed, and (d) for grain for human food. The session today has emphasized the use of oat grain as a food and feed and special traits that might be enhanced to make oats a more valuable crop for these purposes and for industrial uses.

Naked Oats

The topic of at least six papers today was naked oats. Naked oats (i.e., oat caryopses without adhering hulls) have been known and studied for many years[16,24]. They have been classified as a separate species (*Avena nuda* L.)[6] and as a subspecies (*A. sativa nuda*)[23]. Recently, however, all hexaploid species of oats have been classified under one species, *A. sativa*, by Ladizinsky[12]. The naked/covered trait of oats is genetically controlled by alleles at one locus with the naked trait being either dominant, which gives an F_2 ratio of three naked to one covered plants[5,27], or with no dominance, which gives and F_2 ratio of one naked, two intermediate, and one covered plant[4,29].

When used as an animal feed, naked oats have higher energy value per kg than do covered types. This is especially advantageous for monogastric animals and poultry. Cuddeford found that when fed to horses as 60% of the diet, the naked oats significantly increased the digestibility of energy, organic matter, and fat and decreased the digestibility of protein and the absorption of calcium and phosphorus. Farrell showed that metabolizable energy and fat digestibility of naked oats were less for chicks than for adult poultry. When naked oats made up 50% a poultry ration, egg laying was reduced.

Seemingly, naked oats should be advantageous for the milling industry because the dehulling step would be reduced or eliminated. However, because naked oat genotypes produce grain with 5-20% covered seeds, separation of naked and covered seeds is necessary with subsequent dehulling of the covered seeds: Thus, with current naked cultivars, the offsetting operations would probably offer no processing cost reduction for the oat milling industry. However, Burrows has told us that combining the fatuoid and naked traits will give grain that is virtually free of covered seeds. This may be the breakthrough needed for the milling industry to accept naked oats. Valentine related that threshing damage to naked oats, when kept low, does not cause increased rancidity during storage, or problems in crop establishment.

Over 40 years ago, Grafius bred James and Nakota naked oat cultivars for the Great Plains area of the US. Recently, oat breeding has resulted in the naked cultivars Pennuda from Pennsylvania (US); Rhiannon, Kynon, and Pendragon in the UK; Tibor, Terra, AC-Lotta, AC-Belmont, AC-Percy and AC-Hill in Canada, and Bandicoot in Australia. Marshall and Weaver have described incentive programs for enticing farmers to produce naked oats.

Breeding naked oat cultivars can be approached in a couple of ways. The pedigree, single-seed descent, and bulk method requires that one or more of the parents carry the naked allele: Selection is practiced only among naked genotypes. Alternatively, selection could be among covered genotypes, as is the custom now, with conversion of selected lines to the naked genotype via backcrossing. For a population enhancement breeding program based upon recurrent selection, the matings to construct the C_0 could utilize both covered and naked parents, but only naked segregates would be selected as parents in subsequent cycles.

Modifying Composition of Oat Grain

Grain quality of oats, and other cereals as well, has many definitions, usually being determined by the end use of the grain. Quality for "race horse" oats is based upon high test weight and brightness of grain. Quality of oats for the miller is based upon milling yield and brightness of the groats. Indexes to milling yield are test weight and hull percentage. Recently, there is a move to measure quality of oat grain via chemical composition.

Protein

The first major effort to modify the composition of oat grain occurred in the late 1960s. Oat grain has higher protein percentage than other cereals, on average, and some accessions of *A. sterilis* were found to have very high protein percentages; i.e., 25-30%[9,17]. It was assumed that cereal made from high-protein oats would have an advantage in human diets and this might be reflected in expanded markets for oat cereals. Goodland and Dal cultivars, both with groat protein contents above 18%, were released in Wisconsin (US), Proat, a protein line, was released in Minnesota, and Otte, which had a medium high protein content, was released from Illinois (US). The genes for high protein content in these cultivars were derived from the *A. sativa* gene pool. In general, oat cultivars with high protein percentage have been lower in grain yield than those with medium to low protein concentration. Cox and Frey[7] derived *A. sativa* type lines from interspecific matings that derived their high-protein genes from *A. sterilis*, and these lines were used in a study conducted by Kuenzel and Frey[11] on inheritance of yield and protein content. Of 27 matings in the study, they found five in which grain yield and grain protein concentration were not correlated. Segregates from these five matings were used by McFerson and Frey[14,15] to initiate a recurrent selection program for high protein yield. Over three cycles of selection, protein yield was increased 27 kg ha^{-1} cycle^{-1}, but contrary to most other reports, grain yield and groat protein percentage increased simultaneously. Grain yield increased 95 kg ha^{-1} cycle^{-1} and groat protein content increased 0.31% cycle^{-1} and both increases were significant. The genetic correlation between these traits in cycle 3 was 0.13, and the mean protein concentration and grain yield of the five lines with highest protein yield were 20.0% and 3.55 Mg ha^{-1}, respectively. For comparison, Ogle, the highest yielding check cultivar, had grain yield and groat-protein content of 3.31 Mg ha^{-1} and 16.6%, respectively, and Preston cultivar with high protein content had grain yield and groat-protein content of 2.34 Mg ha^{-1} and 19.8%, respectively.

This study was important because it (a) showed the efficacy of recurrent selection for enhancing a quantitatively inherited trait in an autogamous species and (b) demonstrated the existence of a germplasm source in which grain-protein content and grain yield are non correlated. Perhaps similar germplasm sources will be discovered in other cereals.

Oil

Increasing groat-oil percentage of oat is another possible avenue for an industrial use for this crop. It has been estimated that oat grain with 17% groat oil would make oil extraction economical[10]. Branson and Frey[2] described the development of a gene-pool that was constructed to contain genes for high groat-oil percentage from *A. sativa* and *A. sterilis*. Thro and Frey[25] had shown that the high-oil alleles from the two species were diverse and complementary, but no accession of either species had greater than 11% oil. Phenotypic recurrent selection has been applied to this gene pool for six cycles at the rate of one cycle per year. After three cycles, Branson and Frey[2] reported that mean groat-oil concentration was 11.3% and the highest line had 14.5%. Schipper and Frey[20,21] evaluated six cycles of phenotypic recurrent selection on this gene pool and found the mean groat-oil concentration was 14.2% and the highest line had 16.4% groat-oil. In fact, the C_0 and C_6 frequency distributions of oat lines showed no overlap for groat-oil percentage. Third-cycle lines from this gene pool were used to develop oat lines adapted in Scandinavia with 10% oil (B. Mattsson, per. comm., 1992).

ß-glucan

A third oat-groat constituent that has received much attention and publicity is soluble dietary fiber. The beneficial constituent is probably ß-glucan. McDonald, Shinnick, and Ink presented a comprehensive review of clinical studies with oats and oat bran used in human diets. They conclude dietary fiber from oats lowers serum LDL-cholesterol concentrations in humans significantly. In a germplasm survey conducted by Lim *et al.* [13], the ß-glucan concentration of oat groats ranged from 3.0 to 6.0%. Peterson (D.M. Peterson, pers. comm., 1992) has found accessions in the US Oat World Collection with 8.0% ß-glucan. The heritability of ß-glucan percentage with single plants as the selection unit is about 52%. There is little genotype x environment interaction for ß-glucan concentration in oats[19] and gene action for this trait is primarily additive. Gene pools are being constructed to elevate and decrease ß-glucan percentage in oat grain.

Breeding Methods

Breeding methods to use for genetically changing oat seed characteristics and groat composition depend upon short- and long-term goals of the breeding program and the inheritance patterns of the traits to be modified. As noted earlier, the naked seed trait is amenable to backcrossing or being established as the sole state of seed covering in a gene pool that is being enhanced for a quantitatively inherited trait such as yield.

Three constituents of oat groats, protein, oil, and ß-glucan have been studied genetically and they have a great deal of commonality. Percentages of protein, oil, and ß-glucan in oat groats are affected by environment, but generally they show no or a low degree of genotype x environment interaction. That is, the environmental effect in expression of these traits is additive so the ranking of genotypes does not change much from one environment to another. In fact, Schipper and Frey[20,21] showed that selection in the greenhouse was 68% as effective as selection in the field for groat-oil concentration. The heritabilities of oil, protein, and ß-glucan contents vary from 40-60% when a single plant is the selection unit. In other words, the correlation between single plants grown in one environment and their progenies in a second environment is about 0.50. Further, the gene action for these traits is largely additive. The low g x e, relatively high heritability, and additive gene action characteristic of protein, oil, and ß-glucan percentages of oat groats show that their genetic modification will be quite easy to accomplish providing genetic variation is available for these traits. And to date, genetic diveristy for each of these compositional traits has been found.

Generally, any of the seed traits can be enhanced easily. For the short-term, pedigree or single seed descent methods can be used successfully with single, three-way, and double crosses being used as the sources of genetic recombination. However, for the long-term goal of modifying a constituent to previously unattained levels, phenotypic recurrent selection is the plant breeding method of choice. In most circumstances, one cycle of phenotypic recurrent selection can be conducted per year, with the crossing being done in the glasshouse.

Modifying Other Groat Constituents

Other oat groat constituents that have been studied are α-tocotrienols, starch, and fatty acids. Today, Peterson has shown that oats have a high concentration of α-tocotrienol when compared to wheat and maize. There is genetic variation for this constituent and it varies in its distribution in the kernels of diverse genotypes. Oat starch has been studied by White and colleagues at Iowa State University. The starch granules of oats are small (3-10), and therefore, this component may be useful for paper sizing, textiles, pharmaceuticals, and other industrial purposes[3,28]. The amylose content of oat starch ranges from 16-29%[8,18]. Oat starch has a relatively high level of intermediate starch fraction with properties of both amylose and amylopectin[1,18].

The primary fatty acids of oat oil are palmitic at 19%, oleic at 42%, and linoleic at 36%[10]. Stearic and linolenic acids average about 1% each. Oleic and linoleic fatty acids are positively and negatively correlated with groat-oil content. Among 64 lines and cultivars of oats analyzed, the range of oleic acid contents in oat oil was 29-52% and the range for linoleic acid contents was 26-49%. Thro et al. [26] found that heritabilities for fatty acids were 68% for palmitic, 72% for oleic, and 64% for linoleic. Additive gene action was the most important genetic component of variation for all fatty acids. Over six cycles of recurrent selection for high groat-oil content, Schipper et al. [22] showed that significant changes occurred in the fatty acid composition of oat oil. Palmitic acid decreased from 17.5 to 16.0%, oleic acid increased from 43.5 to 48.0%, and linoleic acid decreased from 35.5 to 32.0%.

Starch, α-tocotrienol, and fatty acids of oat groats have not been objectives of oat breeding. Undoubtedly, genetic variation occurs for all of these constituents and probably their inheritance and heritability would be similar to protein, oil, and ß-glucan. If so, breeding to enhance their contents should be successful via the use of the same breeding methodologies.

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Inheritance of ß-Glucan in Oat

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Summary

An experiment was conducted to estimate broad sense heritability of ß-glucan content in oat. Population 1 resulted from the cross 'Garry' x 'Hazel', and population 2 from the cross 'Garry' x 'Marion'. Garry is a low ß-glucan cultivar, while Hazel and Marion have high groat ß-glucan contents. Variance components and heritabilities were calculated for each cross. Absence of discrete classes and normal frequency distributions of S_0-derived lines suggest polygenic inheritance of groat ß-glucan content. Population 2 had a high proportion of positive transgressive segregants, indicating that Marion appears to be a good source of genes for increasing ß-glucan content. Broad sense heritabilities of 0.41 and 0.54 were observed for populations 1 and 2, respectively.

Introduction

Heritability estimates are an important source of information for the plant breeder. An understanding of the magnitude of heritability of a trait facilitates determination of appropriate breeding and selection procedures, and helps predict the relative ease or difficulty of genetic improvement for that character.

Mixed-linkage $(1 \rightarrow 3),(1 \rightarrow 4)$-ß-D-glucan (ß-glucan), a nonstarchy, water-soluble polysaccharide, is an important quality component of oat grain. Numerous workers have demonstrated a hypocholesterolemic response when ß-glucan or other water-soluble fibers are consumed by experimental animals[3] or humans[1]. Despite the significance of this trait, information concerning the heritability of ß-glucan concentration in oat has not been reported.

The objective of this study was to estimate genetic variances and broad sense heritabilities of groat ß-glucan concentration in two segregating S_0-derived oat populations.

Methods

Two S_0-derived populations with nested family structure were developed from crosses made in the greenhouse during March 1990 between oat genotypes with different groat ß-glucan contents. Population 1 resulted from the cross Garry x Hazel, and population 2 from the cross Garry x Marion. F_1 seeds were planted in the greenhouse and 25 F_1 plants were randomly selected and seed from individual plants was grown in the greenhouse in 1990. Single S_1 seeds from two randomly selected plants per S_0 line were harvested at maturity and planted individually in 10 cm pots in the greenhouse on 28 Dec. 1990. S_2 seed harvested from 50 individual S_1 plants per population comprised the lines used for heritability estimation.

Fifty random S_0-derived lines, the two parental cultivars, and a check variety were planted in the field at East Lansing on 3 May 1991. The experimental design utilized was a randomized complete block with two replications. Separate experiments were planted for each population. Individual plots consisted of a 1m row with 30cm row spacing. Approximately 50 seeds were planted per plot. Plots were surrounded by a check cultivar to minimize border effects.

Soil at East Lansing is Capac loam (fine-loamy, mixed, mesic Aeric Ochraqualfs). Fertilizer was incorporated prior to planting at a rate of 64 kg ha^{-1} N, 28 kg ha^{-1} P, and 53 kg ha^{-1} K. Plots were kept weed free by manual cultivation.

Late planting due to early wet conditions was followed by warm, dry weather early in the growing season, which reduced tillering and caused early heading. Total precipitation during the growing season was 171mm.

A single plant per plot was harvested at maturity, threshed, and seed dehulled in an impact type dehuller. Groat samples were ground in a Cyclone Sample Mill (U.D. Corp., Boulder, CO) fitted with a 0.5mm screen. Flour samples were stored in air-tight containers at –20°C until used. ß-glucan concentration was determined by the enzymatic method described by McCleary and Glennie-Holmes[6] and modified by McCleary and Codd[5], using the Biocon ß-glucan kit (Quest-Biocon, Sarasota, FL). Groat flour moisture was determined by oven drying samples at 80°C for 24 hr. Results are reported on a dry weight basis.

ß-glucan data for S_0-derived lines of populations 1 and 2 were subjected to individual analyses of variance. Variance components in the mean square expectations were equated to genetic variance components which were then estimated using weighted least squares. Standard errors for heritability estimates were calculated according to Hallauer and Miranda[2].

Results and Discussion

Mean groat ß-glucan values for populations 1 and 2 and their respective parental cultivars are presented in Table 1. Discrete classes are not apparent in frequency distributions for groat ß-glucan content of S_0-derived lines, suggesting polygenic inheritance of this trait.

Table 1.   Mean groat ß-glucan content and standard errors for the crosses Garry x Hazel and Garry x Marion and their respective parental cultivars grown at East Lansing in 1991.

Population	ß-glucan content (g kg^{-1})	n
Garry x Hazel	48.1 ± 4.4	50
Garry x Marion	56.9 ± 4.4	50
Garry	44.7 ± 1.1	6
Hazel	71.8 ± 0.9	4
Marion	59.0 ± 2.2	4

Chi-square, skewness, and kurtosis values were not significant (P = 0.05) for either population, indicating normality of the frequency distributions.

In the absence of linkage, agreement of cross means with midparental means suggests additive gene action is present[4]. A positive but nonsignificant (P = 0.05) deviation of 8.8% was observed for the mean of population 2 from its midparental value. The mean of population 1, however, had a large, significant (P = 0.001) deviation of –17.5% from the midparental mean. This deviation could be due to dominance with or without epistatic gene action, or to linkage of unfavorable alleles determining ß-glucan content.

The proportion of transgressive segregants with significantly lower or higher groat ß-glucan content than the respective low or high parent varied with the cross. In population 2, 26% of the lines had higher ß-glucan levels than the high parent (Marion) and only 2% had lower ß-glucan levels. The most extreme positive transgressive segregant in population 2 had 23% higher ß-glucan concentration than Marion. In population 1, 16% of the lines had significantly lower groat ß-glucan concentrations than the low parent (Garry), and no positive transgressive segregants were observed. The high proportion of positive transgressive segregants in population 2 suggests that lines with high ß-glucan content could be obtained from crosses utilizing Marion as a parent.

Variance components and broad sense heritabilities are presented in Table 2. Since evaluation of ß-glucan concentration was carried out in advanced (F_4) lines, dominance variance is expected to be small, and most genetic variance should be additive. Therefore, observed heritabilities may approximate narrow sense values. Heritability values reported in this study may be biased upward because the estimate of genetic variance was obtained in one year at one location. Heritabilities estimated in this study are of sufficient magnitude to expect genetic gain from selection. However, since heritability values are intermediate, and genotype interactions with environment are probably important, selection for ß-glucan content in oat should be based on replicated trials in advanced generations.

Table 2.   Genetic (^2_G) and error (^{2}) variance components and broad sense heritabilities (h^2) for groat ß-glucan content in two oat crosses.

Population	δ^2_G	δ^2	$h^2 \pm SE$
Garry x Hazel	13.51	39.38	0.41 ± 0.01
Garry x Marion	22.80	38.34	0.54 ± 0.24

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Total and Extractable ß-glucan Contents of Oats and their Relationship to Viscosity

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Summary

Two diverse collections of oats were used to determine the relationships between viscosity and total groat ß-glucan. The first collection contained 19 genotypes of oats ranging in acid extract-viscosity (AEV) values from 3.4 to 14.4 centiStokes (cS), total ß-glucan 1.8 to 2.8%, pentosans 2.4 to 4.5% and starch 49.0 to 75.2%. The acid buffer (pH 1.5) extracted, on average, 70% of the total ß-glucan, 22% of the pentosans and <1% of the starch. The correlations (r) between AEV and total ß-glucan was 0.43 (P<0.05). In the second collection containing 101 genotypes of oats the correlation between AEV and groat ß-glucan content was even lower (0.27; P<0.01). Twelve genotypes of oats, obtained from the second collection, were extracted with acid buffer and water at pH 6.0 and 10.0. Acid buffer and water (pH 10.0) extracts generally had similar mean viscosities (14.4 and 18.2 cS) and extractable ß-glucan (1.1 and 1.2%); the latter formed 23 and 26% of the total ß-glucan. However, oats extracted with water at ph 6.0 had low mean viscosity (4.0 cS) but a high mean extractable ß-glucan (1.8%), which formed 39% of the total ß-glucan. AEV was a poor indicator of total ß-glucan content in oats. Secondly, pH of extraction influenced both the viscosity and extractable ß-glucan content of oats.

Introduction

Several procedures have been described in the literature for the measurement of ß-glucan in barley and oats. These procedures are based on measuring specific binding of the fluorochrom Calcofluor to ß-glucan, enzymatic hydrolysis followed by measurement of glucose and viscosity. The latter procedure is based on the extractability of ß-glucan in aqueous solvents. Acid extract viscosity (AEV) was reported to be positively correlated with total ß-glucan in barley[1, 2]. Hydrolysis of acid extracts of barley with different enzymes showed that protein or starch present in the extracts had no effect on AEV, which was largely the result of extractable ß-glucan and, to a minor extent, extractable pentosans[3]. The relationship between AEV or extractable ß-glucan to total or groat ß-glucan has not been reported for oats, nor is it known if AEV can be used to predict total ß-glucan in oats, as in barley. The present paper reports on the extractability of oat ß-glucan in different media, the composition of the acid buffer extract and the relationships between extract viscosity and total ß-glucan in diverse collections of oats.

Methods

Two lots of oat were used in the study. Lot 1 contained 19 diverse genotypes of oats grown in 1986 at the University of Saskatchewan, Saskatoon. Lot 2 contained 101 genotypes of oats collected from Canada, U.S.A., Finland, Norway, Wales, Germany, Sweden, Czechoslovakia, Argentina and Australia. The oats samples were dehulled and subsamples of groats ground to a meal (particle size about 0-5 mm) in a Krups coffee grinder and stored at 5°C. Oat meal (1.5 g) was extracted with 15.0 ml of water (pH 6.0 or 10.0 adjusted with solid sodium bicarbonate) or acidic buffer (pH 1.5) for 1 h at room temperature (25°C) in a Udy multiple shaker. The extract was centrifuged at 1000 g for 20 min and viscosity of the supernatant measured at 25°C in a Ubbelohde viscometer and expressed as centiStokes (cS). After measurement of viscosity, the extracts were neutralized, where necessary, and freeze-dried to yield acid- or water-extractable fractions. Groat and extractable ß-glucan, pentosans and starch contents of the freeze-dried extracts were measured, details of the procedures are described elsewhere[4].

Results and Discussion

Lot 1 (n = 19) oats ranged only 3-14 cS (mean 7.3 cS) in AEV, 2 to 3% (mean, 2.3%) in total β-glucan, 2 to 5% (mean, 3.7%) in pentosans and 49 to 75% (mean, 60%) in starch. The acid-buffer-extractable fraction contained 1.2 to 2.0% β-glucan, 0.4 to 1.2% pentosans and 0.2 to 0.6% starch, forming on the average 70, 22 and less than 1% of the groat β-glucan, pentosans and starch, respectively. Thus, the major components of the acid-buffer extract were β-glucan and pentosans, forming on the average 92% of the acid-extractable fraction. Soluble starch formed less than 1% of the groat starch. In view of the extremely low or negligible solubility of starch in acid-buffer, the major contributor to AEV therefore was extractable β-glucan and, to a minor extent, extractable pentosans.

Table 1 shows the range, mean, standard deviation and coefficient of variability in the larger population (lot 2) of oats.

Table 1. Statistical parameters of acid extract viscosity and β-glucan contents of 101 diverse genotypes of oats

Parameter	Acid extract viscosity (cS)	Groat β-glucan (%)
Range	4.5 - 51.7	2.9 - 6.1
Mean	15.6	4.6
Standard deviation	9.4	0.6
Coefficient of variation (%)	60.3	13.0

The correlation between total β-glucan and AEV for lot 1 oats, although significant (r = 0.43), was weak and could not be used to predict total β-glucan in oats by determining AEV. The correlation between total β-glucan and AEV in lot 2 oats was even smaller (r = 0.27). In both the populations, only 7 to 18% of the variability (r^2) in β-glucan could be predicted by AEV. In the larger population (lot 2) each unit increase in β-glucan concentration resulted in an increase of 4.05 cS in AEV. However, variability was so great (r^2 = 0.075) that AEV could not be used to predict β-glucan. Thus, unlike in barley[1-3], AEV does not seem to be suitable for rapid screening of oats for β-glucan which needs to be determined by alternate procedures. Second, pH of extraction influenced both the viscosity and extractable β-glucan contents of oats.

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Correlation of Dietary Fibre with Other Components in Oat Kernel Derived Products

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Summary

In the manufacturing of oat bran minimum fibre levels must be met. Measuring dietary fibre directly requires more time than is normally available before the material must be dispatched after production. A range of other components of oat bran were investigated to see if the levels of any correlated sufficiently with the dietary fibre content to be able to be used to·ensure that the specified fibre levels are present in the product. Among the components tested the ash content of oat bran has proved to be best able to serve this role.

Introduction

The Oat Bran definitions in Australia (Cereal Chemistry Division of the Royal Australian Chemical Institute), the United States of America (American Association of Cereal Chemists) and Germany (Deustche Landwirtschafts-Gesellschaft) all include minimum total dietary fibre (TDF) and/or beta-glucan levels, as can commercial specifications. The measurement of TDF involves a lengthy multi step enzymatic process. The time delay and difficulties involved in measuring dietary fibre make it difficult to fit it in with the commercial production which can require manufacture and dispatch of products the next day. Calculations using the endosperm extracted to check on the quality of the bran produced while theoretically possible are simply not able to be carried out due to the difficulties of auditing a mill during production.

The concept of gauging TDF indirectly using another related and easier to measure component is popular. In North America, protein levels have been used. The protein level is highest in the outer layers of the kernel and as this is also where mainly the fibre is, so when the protein is concentrated so is the dietary fibre and viceversa. Indeed for grain products from a single oat sample this holds (see Figure 1). Unfortunately when it comes to commercial processing involving tens of thousands of tons per year, there is poor correlation between the dietary fibre and protein content of the products produced. This is presumably because of the variation of the protein levels in the oat groats being processed, and occurs even though the grain used is of a single variety grown in a small geographical area of Western Australia.
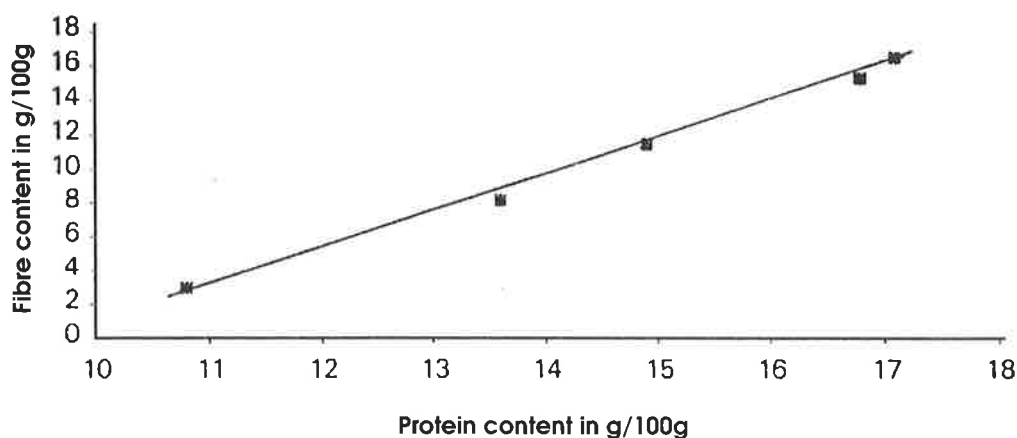
Figure 1. Variation of fibre content with respect to protein content of a milled sample of Norwegian Selma groats, data taken from reference 1.
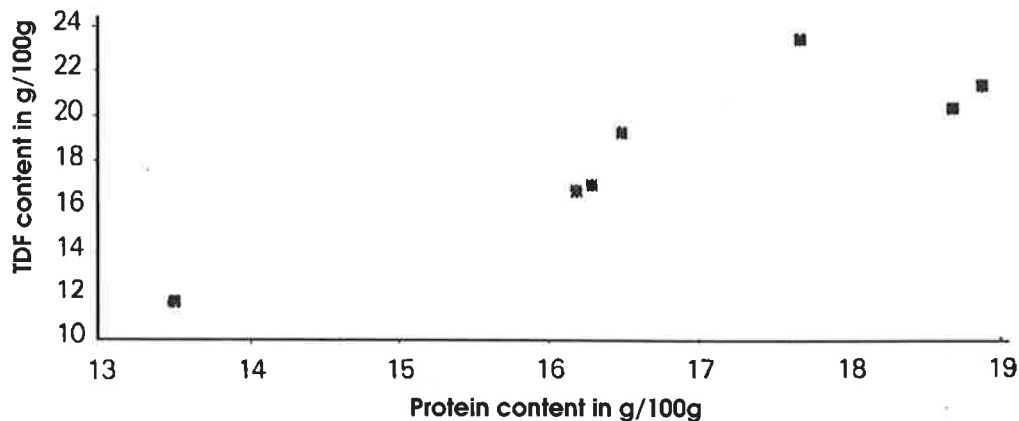
Figure 2. Variation of fibre content with respect to protein content in oat products, produced from Mortlock groats grown in the Williams/Narrogin area of Western Australia, 1989/1990 harvest.

While there have been reports correlating the variation of fibre with other components in oat groats, oat brans have not been so well studied. A number of the factors which have proved to correlate to the groat fibre content such as grain size[2], are not able to be used for oat brans. A review of the other components comprising oat bran products was therefore undertaken.

Methods

The oat products were all made from lipase stabilised Mortlock cultivar groats, the groats being grown in the Williams-Narrogin area of Western Australia.

All results are on dry weight basis. Total dietary fibre was measured by the AOAC (Prosky) method 985.29, Beta-Glucan by either AACC method 32-22 or the MegaZyme Biocon kits (no significant difference being observed between the results of the two methods), ash by incineration for 15 hours at 580°C or until light grey, though 6 hours at 600°C also proves adequate, protein measured by Kjeldahl and calculated as organic Nx5.83, individual minerals by ash digestion followed by measurement by inductively coupled plasma spectrometer, fat via acid digestion followed by extraction with mixed diethyl ether/petroleum ether solvent. Starch was either measured directly enzymatically during the measurement of dietary fibre by the Englyst method or calculated by subtraction of the aggregate of TDF, protein, moisture, fat, and ash contents from a sample, moisture by AACC method 44-15A.

The work was restricted to products of commercial milling operations and represented actual rather than potential products, for example the oat flour contained flecks of bran material rather than being pure endosperm. When the flour produced as a by-product from bran B is sieved on a 300 micron screen the ash content of the material falls from 0.6 to 0.3%.

Results and Discussion

Of the components investigated starch, which was measured either directly or calculated by difference, was found to be inversely correlated with the TDF of oat brans, see Figure 3. This relationship can hold also in groats[2]. Starch measurement, however, like dietary fibre, is not able to be measured very quickly.

Fat content correlates poorly having a significant natural variation in Mortlock groats (8.4–9.5%) and there being only a slight enrichment with increasing endosperm extraction.

Ash content though has proved to be adequate to monitor the total dietary fibre of processed oat brans, see Table 1 and Figure 4.
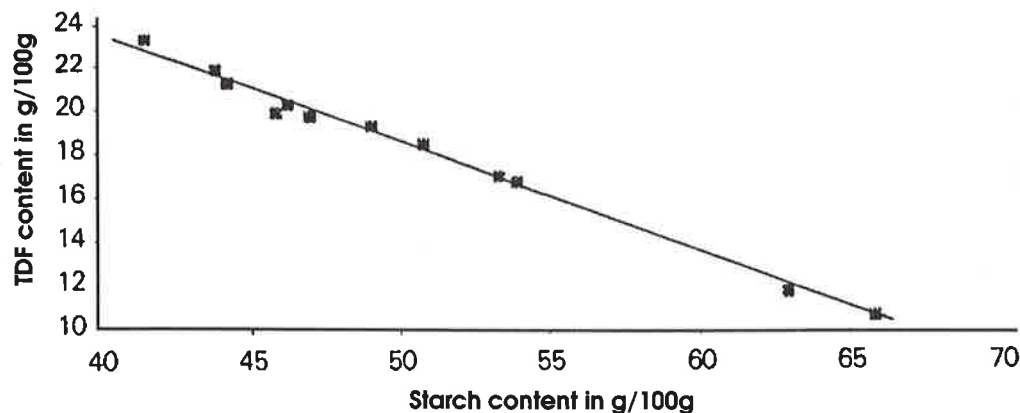
Figure 3. Variation in fibre content with respect to the calculated or measured starch content in oat products made from cv. Mortlock groats grown in Western Australia.
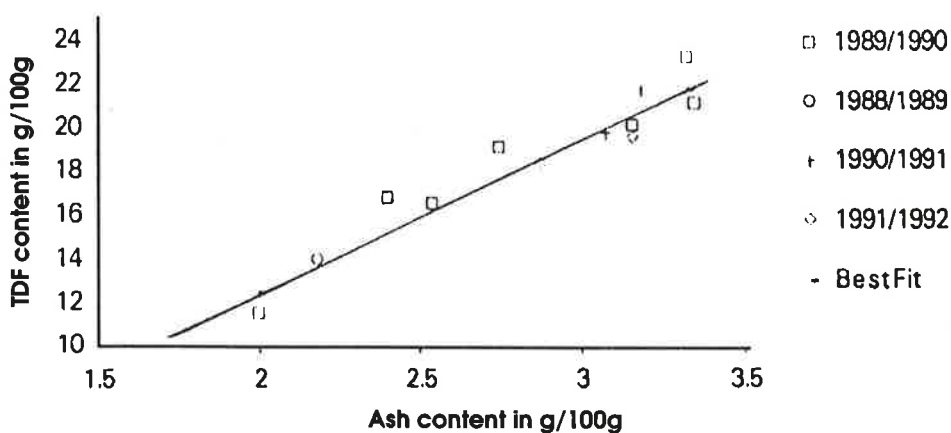
Figure 4. Variation in fibre content with respect to the ash content of oat products made from cv. Mortlock groats grown in Western Australia.

There is a clear linear relationship between the two components and this indicates that there is only minor variation of these in the original groats. The correlation coefficient for the changes in ash and total dietary fibre with extraction of endosperm is 0.97 and this figure may well reflect the inherent difficulties in measuring dietary fibre accurately. With the beta-glucan component of the fibre there is also a linear relationship to the ash content of the products (Figure 5), but here the natural variation in the measured values in the original groats and the products made from the groats is greater but the ash content is still able to be used as an approximate guide.
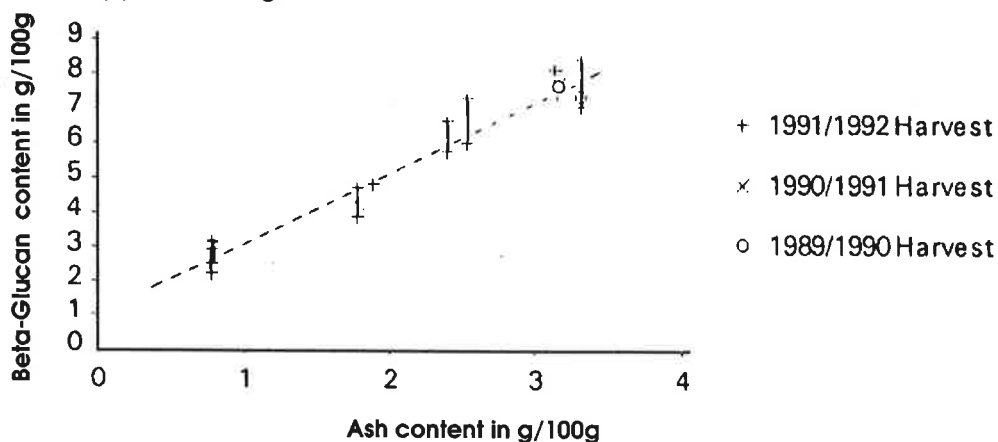
Figure 5. Variation in beta-glucan content with respect to the ash content of various oat products made from cv. Mortlock groats grown in Western Australia.

Table 1.   Contents of total dietary fibre and ash in oat brans and other products
produced from Mortlock groats grown over several seasons
in Western Australia. Contents are on dry weight basis.

Oat Product	TDF Content (grams/100g)	Ash Content (grams/100g)	Harvest Season of grain used
Rolled Oats	10.6	1.78	1991/92
Quick cooking rolled oats	11.7	2.00	1989/90
Semi-bran	14.1	2.18	1988/89
Oat Bran A	16.6	2.54	1989/90
Oat Bran B	16.9	2.40	1989/90
Oat Bran C	18.4	2.88	1991/92
Oat Bran D	19.2	2.75	1989/90
Oat Bran E	19.6	3.16	1991/92
Oat Bran F	19.8	3.08	1990/91
Oat Bran G	20.2	3.16	1989/90
Oat Bran H	21.2	3.35	1989/90
Oat Bran I	21.8	3.19	1990/91
Oat Bran J	23.3	3.33	1989/90

Of course to ensure the meeting of specified levels of dietary fibre, the lower edge of the range of fibre content expected for the measured ash value is to be used rather than the average. Under mill conditions ash has proved to be a reliable indicator and an effective way for picking up a fall in endosperm extraction rate after equipment alteration. Naturally these applications are able to be used only when grain of a single cultivar is being processed and its ash-fibre relationship is known.

A review of the scientific literature was able to find only one other study measuring both ash and fibre in fractions produced from groats of a single oat variety. These measurements (see Figure 6) show the same approximately linear relationship applies for more than the single Australian cultivar so far investigated, though the endosperm extraction did not extend so far.
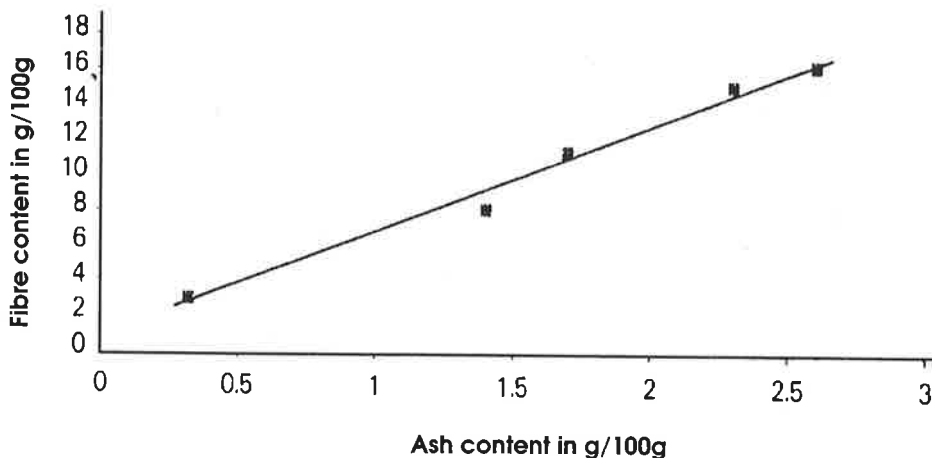
Figure 6.   Variation of fibre content with respect to ash content of a milled sample
of Norwegian Selma groats, data taken from reference 1.

Probing the relationship further, individual components of the ash fraction — potassium, magnesium, calcium, phosphorus, sulphur, iron, zinc, copper and manganese were also examined for their correlation to dietary fibre content. For almost all of the minerals examined there is a clear though broad trend of increasing content with increased endosperm removal and TDF content. A selection are shown in Figure 7. As with fat and protein, there is a significant variation in the content of the individual minerals in the groats. Enrichment during the endosperm extraction is insufficient to overcome this variation and to yield concentrations able to be used to monitor the fibre quality of the bran produced. For copper the amount measured ranged between 4.5 and 5.1 ppm (4 samples) and was lower in the separated oat flour (3.9 ppm, one sample). Variation in copper levels is such that there was effectively no correlation between the metal content and the degree of endosperm removal (see Figure 7d).
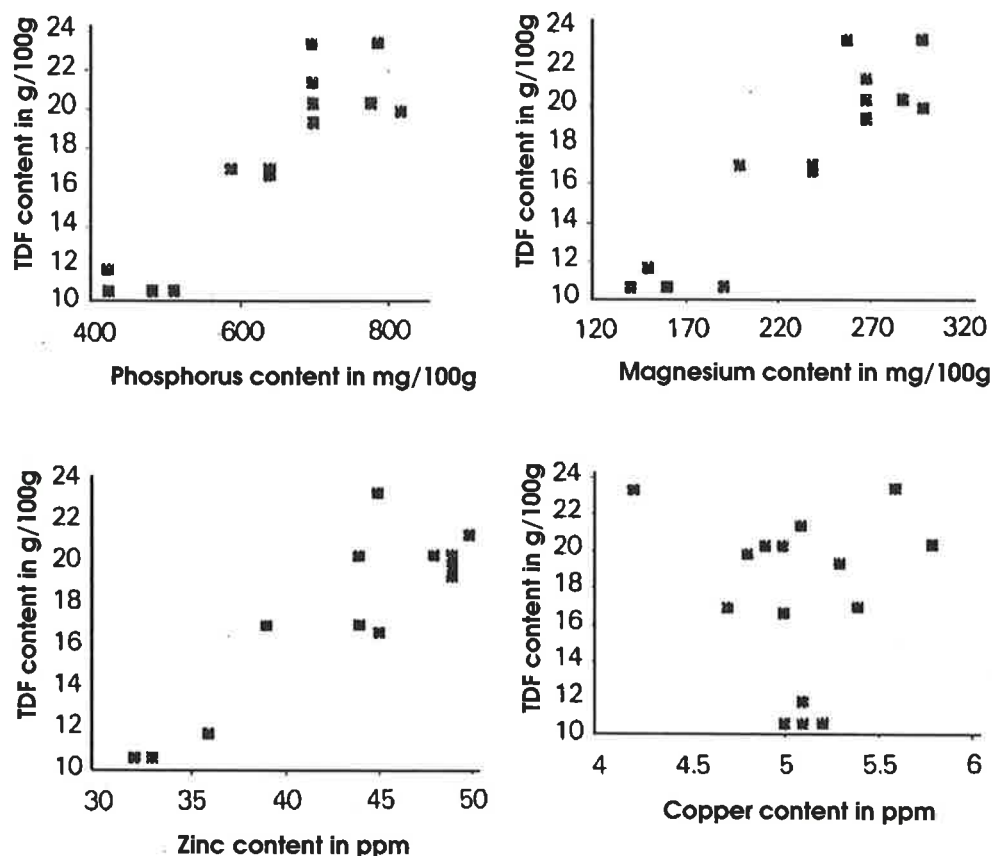
Figure 7. Variation of fibre content with respect to different individual components of the ash in oat products made from cv. Mortlock groats grown in Western Australia. (a) Phosphorus, (b) Magnesium, (c) Zinc and (d) Copper.

The linear relationship between the content of ash and dietary fibres indicates not only that there exists a small enough variation in these components in the groat and that the difference between their concentrations in the endosperm and the bran layers is reasonable but also that the endosperm material being separated from the bran layers during bran production has a composition essentially uniform with respect to these components. Apparently at least up to the production of a bran with an ash content of 3.3 the subaluerone layers are remaining attached and not being extracted. Of course it is not necessary for the bran layers to be similarly uniform in composition as the endosperm or even for more than one layer in the multi layered material referred to as oat bran to have a higher ash content than the endosperm for the relationship to hold. However like the various dietary fibres the distribution of ash is probably different in each of the differing outer layers of the oat kernel. In 1986[3], it was stated that "Unfortunately, a notable shortage of detailed studies relating to groat morphology and microchemistry exists in the literature." At least for minerals both individually and in total this still holds.

A further use for ash measurements in oat products could be had by obtaining the ash content of pure endosperm material for individual oat varieties and comparing them with the ash figures for bran made from the same variety. One should be able to calculate the endosperm extraction rate necessary to obtain such brans.

Acknowledgments

A.Liwszyc — Document Preparation

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Oat Bran — An Australian "Definition"

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Summary

Several varieties of de-hulled oats from growing sites in Western Australia, South Australia, Victoria and New South Wales were tested for kernel weight and a range of components: moisture, protein, fat, ash, total dietary fibre and ß-glucan. This composition was compared with the definition of oat bran and various samples of "commercial" oat bran. Significant relationships were found for site and variety with kernel weight and some other components. Western Australian groats were significantly higher than those from south-eastern Australia with respect to kernel weight, protein, dietary fibre and ß-glucan content.

Introduction

"Oat bran" (as well as oats) has gained considerable recent interest as human food, due to the body of evidence indicating its beneficial physiological effect of reducing serum cholesterol in hypercholesterolaemic patients. It is suggested that this activity is associated with ß-glucan, the major component of oat soluble dietary fibre. However, analysis of commercial products indicates a wide range in dietary fibre contents. In an attempt to reduce confusion and provide an industry guideline, a definition for oat bran was adopted by a gathering of Australian processors and scientists at Cereals International 91 in Brisbane, September, 1991. This was largely the same as that of the American Association of Cereal Chemists. It is based on minimum specification of total dietary fibre (16%) and ß-glucan (5.5%), both expressed on a dry basis, with soluble dietary fibre at least one third of the total dietary fibre. However, as relatively little is known about the range in composition of Australian oats it was also agreed that the definition be reviewed in the light of results from studies of Australian oats. This study is intended to provide preliminary compositional information from a limited number of oat varieties and sites.

Methods

Oat samples were sought covering a range of varieties and growing conditions. Samples from south-eastern Australia (SEA) were kindly provided by R. Ganly (The Uncle Tobys Co.) and from Western Australia (WA) by R. Wallace (Southern Foods Ltd.) from a breeding trial of Robyn McLean (WA Department of Agriculture). Both sets of samples were supplied as de-hulled oat grain (groats) and tested for kernel weight (Numigral grain counter). After grinding on a Falling Number mill, samples were analysed for: moisture (loss in weight after one hour at 130°C), protein (kjeldahl N x 5.83), total fat (acid-hydrolysis), ash (580°C for fifteen hours), total dietary fibre (AOAC) and total ß-glucan (Megazyme streamlined method). All tests were performed in duplicate. Hand-sieving was performed without sieve aids on 10g ground samples using 250 and 125 standard brass sieves (BS 410) until two consecutive one minute sievings produced less than 1% change in weight. Compilation was also made from Bread Research Institute files of total dietary fibre results from different "commercial oat brans" supplied for analysis.

Results and Discussion

Groats

Averaged results of analysis of groats are shown in Table 1. Despite the relatively small number of data, analysis of variance indicated that site, variety and site x variety had significant effects on oat kernel weight, protein, fat and ash contents. These effects were also significant for dietary fibre and ß-glucan contents of the WA samples.

Mt. Barker is a higher rainfall area than Wongan Hills, as is confirmed by the larger kernel weights and lower protein contents of oats from Mt. Barker. Differences in fibre and ß-glucan contents between varieties were significant for WA samples, with Dalyup the highest in both components ($p < 0.01$). The ß-glucan content of Dalyup from Wongan Hills is unexpectedly high, compared with other data. This anomaly has been observed on another occasion (R. Wallace, pers. comm., 1992). The reason that varietal differences were not significant for Bordertown and Mango samples can be attributed to the smaller number of data. When other SEA Echidna and Mortlock data were added, the difference between their ß-glucan contents became significant, with Mortlock having the higher levels ($p < 0.05$).

Table 1.   Oat quality/composition 1991 season.

Variety	Site	State	Kernel weight (mg)	Protein (Nx5.83)	Fat	Ash	Total dietary fibre	ß-Glucan
							(%) (dry basis)	
(a) South-eastern Australia								
Echidna	Bordertown	SA	28.7	11.5	11.2	1.74	9.3	3.5
Echidna	Mango	NSW	23.0	12.8	11.0	1.68	9.4	3.5
Mortlock	Bordertown	SA	26.9	10.5	11.0	2.04	9.0	3.5
Mortlock	Mango	NSW	23.1	16.4	10.3	1.85	9.5	4.1
Echidna	Lake Bolac	Vic	24.8	9.2	12.1	1.48	8.4	3.2
Echidna	West.Dist.	Vic	25.7	12.1	11.3	1.35	9.1	3.3
Mortlock	Yerrong Ck	NSW	27.9	13.6	10.6	1.81	9.4	3.6
Wallaroo	Kerang	Vic	23.4	13.0	11.9	1.78	9.3	3.4
Yarran	N/A	NSW	30.6	13.6	12.4	1.22	9.3	3.2
X-bred	N/A	SA	26.7	15.3	9.0	1.73	10.2	4.1
(b) Western Australia								
Dalyup	Mt Barker		28.9	15.8	11.3	1.42	10.7	4.0
Dalyup	Wongan Hills		23.2	18.2	9.6	1.76	10.9	5.4
Mortlock	Mt Barker		34.9	16.1	10.9	1.55	9.5	4.2
Mortlock	Wongan Hills		28.5	17.0	10.0	1.71	10.9	4.2
Swan	Mt Barker		35.5	13.1	10.7	1.27	9.5	3.9
Swan	Wongan Hills		32.4	15.0	9.7	1.48	9.8	4.2
X-bred	Mt Barker		32.7	14.6	11.0	1.35	9.4	4.0
X-bred	Wongan Hills		28.1	16.1	9.0	1.54	10.5	3.9

WA oats were significantly higher than SEA samples with respect to dietary fibre and ß-glucan contents, shown in Figure 1 and also kernel weight and protein. Overall levels of ß-glucan are slightly less than other reports on Australian oats[1,2]. Comparisons with other reported protein and fat data is complicated by a general absence of the nitrogen to protein conversion factor and by whether free fat or total fat is measured. However, it appears that SEA protein levels may be lower[3] and fat contents generally higher than overseas reports[4].

Soxhlet fat (free fat) was measured on samples with lowest and highest total fat giving figures that were an average of 1.9% lower than total fat contents (measured by solvent extraction after acid hydrolysis). Correlations indicated a negative relationship between dietary fibre and kernel weight from WA data. From SEA data and combined WA plus SEA data, dietary fibre and ß-glucan contents were positively correlated to protein but negatively correlated with fat content.

(a)

```
                                    4.2W
                     3.9W           4.2W
                     3.8W           4.2W
          3.4V       3.6N           4.1S
          3.3V       3.5S           4.1N
          3.2V       3.5S           4.0W
          3.2V       3.5N           4.0W              5.4W
        _____
          3.0        3.5            4.0        4.5         5.0
                          ß-Glucan (% dry basis)
```

(b)

```
                     9.4W
                     9.4N
                     9.4N
                     9.3S
                     9.3N       9.8W
                     9.3V       9.5W                  10.9W
                     9.1V       9.5W       10.5W      10.9W
          8.4V       9.0S       9.5N       10.2S      10.7W
        _____
  8.0      8.5        9.0        9.5        10.0       10.5
                   Total Dietary Fibre (% dry basis)
```
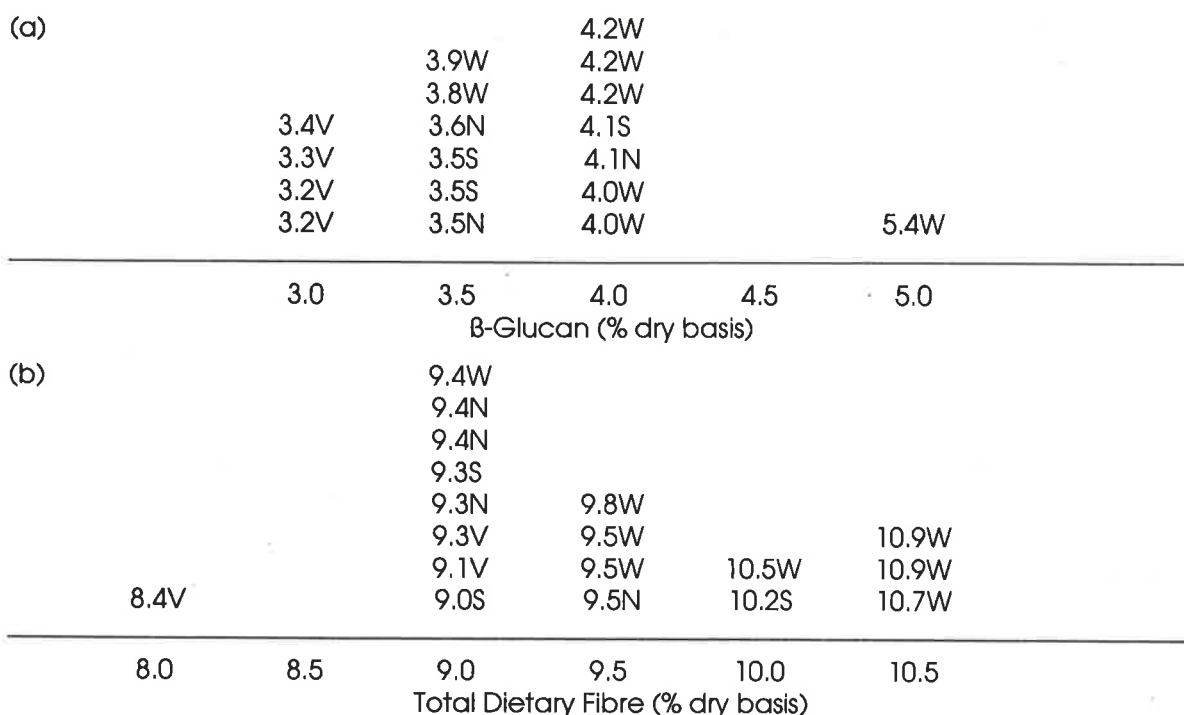
Figure 1. Frequency distributions of groat (a) ß-glucan and (b) total dietary fibre contents, with codes showing the state where grown: N = New South Wales, V = Victoria, S = South Australia, W = Western Australia.

There appears to be no test scale equipment for examining "processability" of groats, so laboratory scale sieving was performed on the ground oats to obtain some indication of ease of processing. Results indicated that the most significant factor effecting yields of coarse and fine fractions was grain moisture content. There was insufficient sample to assess the composition of these fractions, but the high ash contents of 2.6 to 3.4% (dry basis) indicate that the coarse material was high in dietary fibre. This is probably analogous to the conditioning of wheat with water, prior to milling, which is standard practice to achieve cleaner separation of flour from bran. The relationship between ground grain moisture content and sieving yield of coarse material is shown in Figure 2.
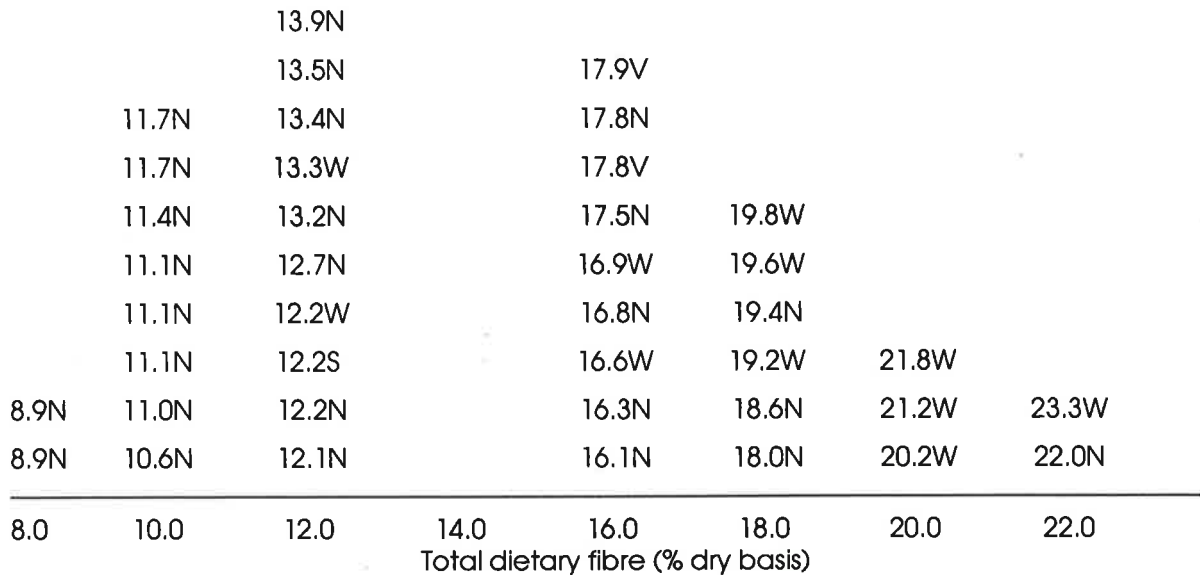

$r = 0.986$
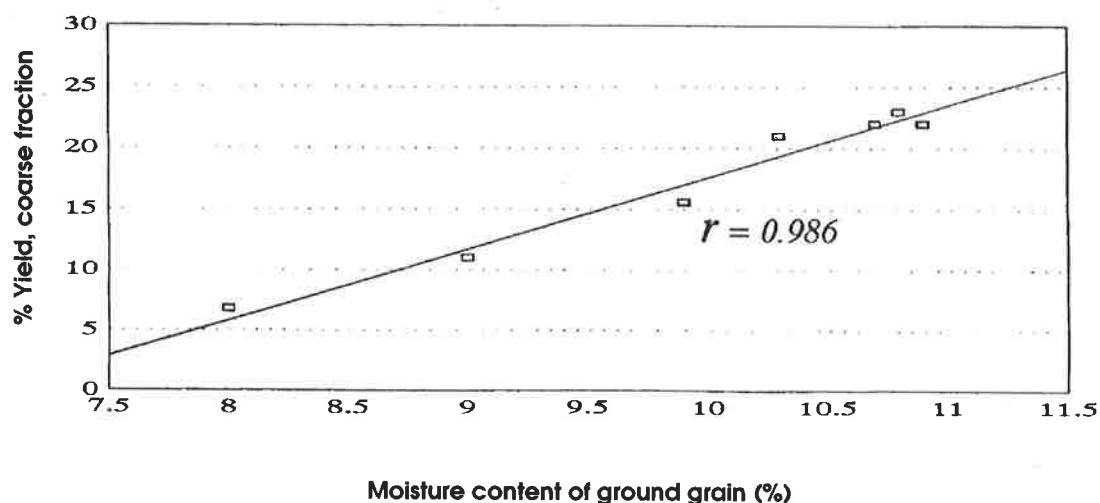
Figure 2. Effect of ground groat moisture content on sieving yield of coarse material (>250µ).

"Oat bran"

Various "commercial oat bran" samples submitted to the Bread Research Institute for dietary fibre analysis are shown in Figure 2. Some of these may have been experimental samples, but it is apparent that some "brans" have fibre contents similar to the levels found in groats. The discontinuity in the mid-range of dietary fibre values suggests this might be the boundary between plain groats and groats receiving further processing. However, in this study, the maximum groat dietary fibre content was 10.9% (dry basis).

```
                     13.9N

                     13.5N          17.9V

          11.7N      13.4N          17.8N

          11.7N      13.3W          17.8V

          11.4N      13.2N          17.5N    19.8W

          11.1N      12.7N          16.9W    19.6W

          11.1N      12.2W          16.8N    19.4N

          11.1N      12.2S          16.6W    19.2W    21.8W

 8.9N     11.0N      12.2N          16.3N    18.6N    21.2W    23.3W

 8.9N     10.6N      12.1N          16.1N    18.0N    20.2W    22.0N
_____

 8.0      10.0       12.0      14.0    16.0     18.0     20.0     22.0
                     Total dietary fibre (% dry basis)
```

Figure 3.   Frequency distribution showing dietary fibre contents of samples of "oat bran" analysed at the Bread Research Institute with codes indicating the state of origin, as for Figure 1.

In order to reach a suggested dietary fibre level of 16% (D.B.) in oat bran, an enrichment factor of approximately 1.6 would be sufficient for half of the WA oat samples (fibre contents at least 10%), but a factor of 1.8 would be required for SEA oats with fibre levels as low as 9%.

It may be due to the limited nature of this study that no one oat variety has been identified as having with a consistent high dietary fibre or ß-glucan content, although it may be useful to investigate the anomalous high ß-glucan value for Dalyup. Only a limited number of growing regions have been sampled, for one growing season, so it has not been conclusively established that WA gives higher protein and fibre grain whilst SEA gives oats of higher calorific value. However, it appears that the fibre requirement of the present definition for oat bran is more difficult for processors with access limited to the SEA groats with the composition indicated in this study.

Much more extensive studies are required, though with costs balanced against the expected value of oat products for human food compared with animal feed.

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Effects of Genotype X Environment Interaction on the Expression of Grain Quality Traits in Oat

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Summary

Fourteen oat genotypes were grown at 3 locations in 1989 and 1990 to investigate whether there are sufficient genetic variations among western Canadian oat genotypes in beta-glucan content, oil content, protein content, and groat content; to assess the relative importance of genotype, location and season on the expression of these characteristics; and to determine the extent of phenotypic, genotypic and intra-genotypic correlations that may exist among the four physicochemical traits. The results showed that location was the most important factor that affects the quality of western Canadian oats. Genotype x environment interaction effects were relatively small. The phenotypic correlations among pairs of the four traits were either positive (P<0.01) or insignificant, and the corresponding genotypic correlation coefficients were not significant. These suggested that there will be very little restriction to concurrent improvement of desirable combinations of the four traits.

Introduction

In the prairies of western Canada, oat *(Avena sativa* L.) is an important cereal crop grown either in monoculture or in mixture with legumes, particularly alfalfa *(Medicago sativa L.).* Improvements of its physicochemical traits such as energy value, protein content, test weight, kernel plumpness and beta-glucan content to fit the quality specifications of the milling and animal feed markets would make oat an even more valuable crop in Canada as well as in many other parts of the world.

The oat production areas in western Canada are environmentally diverse in precipitation, growing-degree-days, soil types and crop management practices. Although the marketing of oat has become increasingly linked to quality standards, the effects of genotype, environment and their interaction on oat quality have received very little research attention. In addition, little is known about the genetic variability that exists among western Canadian oat cultivars and the potential for manipulating their quality through plant breeding. This study was conducted: (1) to investigate whether there are sufficient genetic variations among western Canadian oat cultivars in beta-glucan content (BGC), oil content (OC), protein content (PC), and groat content (GC); (2) to assess the relative importance of genotype, location and season on the expression of these characteristics; and (3) to determine the extent of phenotypic, genotypic and intragenotypic correlations that may exist among the four physicochemical traits.

Materials and Methods

In 1989 and 1990, 14 oat genotypes were grown at 3 locations in Alberta, (Lacombe (Black Soil), Breton (Grey Wooded Soil) and Beaverlodge (Dark Grey Wooded Soil)) to study the effects of location and season on grain quality of oats. The experiment at each location was arranged in a randomized complete block design with 3 replications. At Lacombe and Breton, plots were 3 m long with a 23 cm spacing between rows. At Beaverlodge the plots were 5 m long with the rows spaced 23 cm apart. The land used at each location was summer fallowed in the previous year. Fertilizer was applied according to soil test recommendations. Cultural practices of tillage and pest control varied from location to location. but generally were the most appropriate for the respective locations.

Grain samples from each experiment were dried to approximately 12% moisture and cleaned prior to quality analyses. GC was determined using a laboratory size impact dehuller. The calcofluor method was used to determine BGC. OC determinations were made with a Newport Model IV NMR (nuclear magnetic resonance) analyzer equipped with a built-in integrator. A NeoTech Model 51-A NIRS (near infra-red reflectance spectroscopy) instrument interfaced with an IBM PC computer was used to determine PC. The BGC, OC and PC determinations were made on dry groat basis. For each of the four traits, the error variances across the 6 (3 locations x 2 years) environments were found to be homogeneous according to Bartlett's test. Therefore, a combined analyses of years, locations, genotypes and their interactions were performed to determine the relative contributions of the main effects and their interactions. In addition, phenotypic, genotypic and intra-genotypic correlation coefficients were calculated for all possible pairs of the four traits.

Results and Discussion

The 1989 and 1990 crop seasons were generally satisfactory for growing oat. In both years, a warm spring with adequate soil moisture provided excellent conditions for uniform germination and good stand establishment. However, drought, and hot and windy periods in June and July affected the 1989 plots at Beaverlodge and Breton, and caused early maturity and reduced grain yield. As a result, BGC, OC, and GC were higher, and PC lower in 1990 than in 1989. Genotype means averaged over the 6 environments ranged from 3.4 to 4.7% for BGC, from 15.4 to 21.5% for PC, from 7.0 to 9.5% for OC, and from 68.9 to 93.8% for GC. Location means for BGC and GC averaged over the 14 genotypes and 2 years were highest at Lacombe and lowest at Breton, whereas location mean for OC was highest at Breton and lowest at Lacombe. The highest (19.0%) and lowest (16.3%) PC means were obtained at Beaverlodge and Lacombe, respectively.

Phenotypic correlations among the four traits were either positive (P<0.01) or insignificant (Table 1), and the corresponding genotypic correlation coefficients were not significant (data not presented). These suggested that there will be very little genetic restriction to concurrent improvement of desirable combinations of the four traits. The 14 genotypes showed no significant differences in intra-genotypic correlation coefficients among the four traits. The ranges of the intra-genotypic correlation coefficients were: BGC with OC (from +0.219 to +0.875), BGC with PC (from -0.793 to -0.068), BGC with GC (from +0.452 to +0.884), OC with PC (from -0.743 to -0.196), OC with GC (from -0.097 to +0.021), and PC with GC (from -0.670 to 0.437), none of which were significantly different from each other at the P=0.05 probability level. The uniformity among these intra-genotypic correlation coefficients indicated that environmental variations generally affected the relationships among the 4 physicochemical traits in a similar manner across all genotypes.

Table 1. Phenotypic correlations between pairs of physicochemical traits of 14 oat genotypes grown at 3 locations in 1989 and 1990.

Characteristics			r	p$
Groat content	'vs'	Oil content	0.029	0.775
		Protein content	0.212*	0.038
		Beta-glucan content	0.328**	0.001
Oil content	'vs'	Protein content	-0.014	0.890
		Beta-glucan content	0.069	0.506
Protein content	'vs'	Beta-glucan content	-0.096	0.352

$ Probabilities > /R/ under Ho Rho = O.
*,**   Significant at P = 0.05 and P = 0.01, respectively.

Analyses of variance pooled over the 6 environments (Table 2) revealed that for each of the four traits, location, year and genotype effects were highly significant (P<0.01). Also for each trait, location had a greater influence than year or genotype effects. These results suggested that there is only a narrow range of genotypic variation among western Canadian oat cultivars on which to base selection for BGC, PC, OC and GC, and that environmental factors may have greater influence than genetic factors on the expression of these traits. The very large and significant location effects on BGC, PC, OC and GC were probably due to aluminum toxicity problems at Breton. If this is true, breeding for aluminum tolerance could provide a new opportunity for grain quality improvement of oat grown in aluminum toxic soils of western Canada. The first and second order interaction effects were generally not significant, and indicated that BGC, PC, OC and GC may vary from location to location and from year to year, but the rank of the genotypes will be quite similar under various sets of environmental conditions. Variance component analyses (data not presented) revealed that the genotype x location, genotype x year and genotype x location x year interaction effects were significantly smaller than both location effect and genotype effect alone. These relatively genotype x environment interaction variance components revealed that preliminary quality evaluation of early generation material, as are needed in breeding programs, can be done on samples collected from only a few environments.

Table 2. Results from combined analysis of variance for beta-glucan content (BGC), oil content (OC), protein content (PC) and groat content (GC) of 14 oat genotypes grown at 3 locations in 1989 and 1990.

Source of Variation	d.f.	OC	GC	PC	BGC
Replication	2	0.6815	2.9656	5.5726	0.0822
Genotype (G)	13	9.0050	785.0432	44.8842	4.9041
Location (L)	2	24.6548	993.4006	253.9656	11.7565
Year (Y)	1	22.9854	71.7305	156.0797	1.1308
GxL	26	0.7312	9.7922	1.1798	0.1602
GxY	13	0.9909	5.1173	2.9401	0.1248
GxLxY	28	0.6073	24.5232	11.5074	5.0031
Error	152	0.1682	0.8075	0.7265	0.2552

Interlaboratory Evaluation of ß-Glucan Analysis Methods

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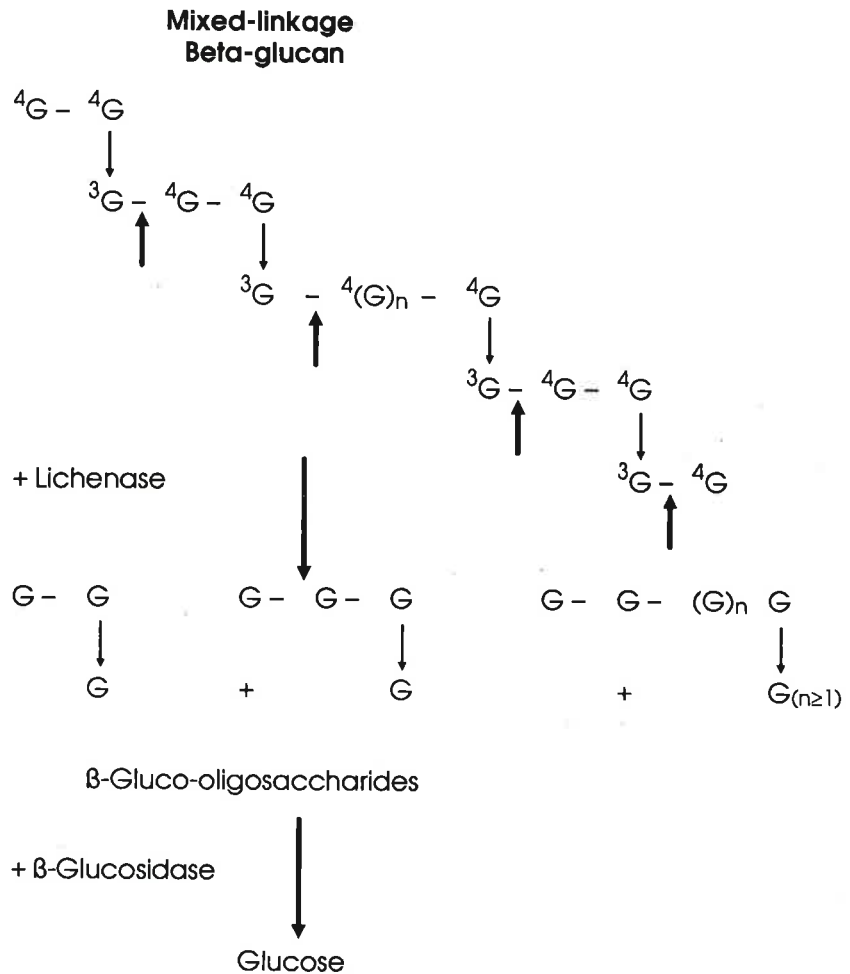[2] Bread Research Institute of Australia Inc., 51 Delhi Road, North Ryde, NSW, 2113, Australia.

Summary

The results of an interlaboratory evaluation of two methods for the measurement of ß-glucan in oat products are compared. In AACC Method 32-22, the format employed is essentially the same as that originally reported by McCleary and Glennie-Holmes (1985) with the modification that the incubation steps were extended and that continuous stirring was introduced into the lichenase treatment step. These modifications were not likely to have a deleterious effect on the assay because of the high purity of the enzymes used. However, as shown clearly in this study, the changes have not improved the accuracy or reliability of the method. In contrast, the changes introduced by us in developing the Streamlined Method, greatly simplify the method with no loss in accuracy or precision.

Introduction

In this paper we report on the results of an interlaboratory evaluation of two methods for the measurement of mixed-linkage ß-glucan in oat flours and cereal products. This evaluation was approved by the Fibre Subcommittee of the American Association of Cereal Chemists at the 1991 Seattle meeting and has been performed according to AACC and AOAC guidelines. The methods under evaluation and comparison are the Megazyme Streamlined Method and AACC Method 32-22. Both of these methods are modifications of the procedure developed by McCleary and Glennie-Holmes[1], and both use lichenase and ß-glucosidase enzymes supplied by Megazyme (Aust) Pty. Ltd.

The principle of this assay is shown in Figure 1. Cereal flour slurries are cooked to hydrate and gelatinise the ß-glucan, which is subsequently hydrolysed to soluble fragments with lichenase enzyme. An aliquot of this solution after volume adjustment, pH adjustment and filtration (or centrifugation) is treated with ß-glucosidase which gives complete and specific hydrolysis of the ß-gluco- oligosaccharides (released on hydrolysis of ß-glucan by lichenase) to D-glucose. The D-glucose is then measured with high-purity glucose oxidase/peroxidase reagent. Parallel aliquots of the lichenase hydrolysate are treated directly with glucose oxidase/peroxidase reagent to give a measure of the level of free glucose in the flour or cereal sample. In situations where the level of free glucose is likely to be high (e.g. some breakfast cereals) the sample is first extracted with 80% aqueous ethanol as described previously for malt flour samples[3].

In the AACC modification of this procedure (Method 32-22)[2], several steps were introduced which make the method tedious and laborious, on the suggestion that the original method[1], as supplied in Diagnostic Kit form, gave an under- estimation of the ß-glucan content. Furthermore, the procedure requires the use of some equipment not usually found in a cereals analytical laboratory, e.g. high speed centrifuge and apparatus for continuous stirring at controlled temperature. These modifications reduced the numbers of samples which could be handled by a single analyst in one day from 80-100 to about 20. In the Megazyme modification (Streamlined Method) of our original method, the aim was to simplify the procedure and to make it more robust, without any loss in precision, accuracy or reliability. In this modification, 30-40 flour samples can be analysed in less than two hours (more than a hundred samples per day) and most of the analytical steps are performed in a single test-tube.

**Mixed-linkage
Beta-glucan**

$^4G - {}^4G$

$\downarrow$

$^3G - {}^4G - {}^4G$

$\uparrow$

$^3G \quad - {}^4(G)_n - {}^4G$

$\uparrow$

$^3G - {}^4G - {}^4G$

$\uparrow$

$^3G - {}^4G$

$\uparrow$

+ Lichenase

$G - G \qquad G - G - G \qquad G - G - (G)_n \; G$

$\downarrow \qquad\qquad \downarrow \qquad\qquad \downarrow$

$G \qquad + \qquad G \qquad + \qquad G_{(n \geq 1)}$

ß-Gluco-oligosaccharides

+ ß-Glucosidase

$\downarrow$

Glucose

Figure 1.   Representation of the reactions involved in the measurement of
ß-glucan using lichenase and ß-glucosidase.

The methods employed were AACC Method 32-22 and the Megazyme Streamlined
Method as outlined in McCleary and Codd[4] and in the Mixed-Linkage ß-Glucan data
sheets supplied with the Megazyme ß-Glucan assay kit. The study was a split level design
with five pairs of samples which were analysed in replicate by eight participating
laboratories by each of the two methods, using the enzymes and reagents supplied. Two
control samples were provided in order to gain experience with the methods. Test samples
were Australian oat products (supplied by Dr. R Wallace, Southern Foods Group, Forrestfield,
WA, 6058, Australia) including whole groat, flour and bran; and breakfast cereal, as listed
below:

A.   Oat flour, byproduct of "super bran" production;
B.   Flaky oat bran;
C.   Oat bran breakfast cereal, packet 1;
D.   Quick cooking rolled oats;
E.   Oat flour, byproduct of "premium bran" production;
F.   Standard oat bran;
G.   Premium oat bran;
H.   Porridge rolled oats;
I.   Instant oat bran;
J.   Oat bran breakfast cereal, packet 2.

Laboratories involved in this study were, University of Maine, USA; University of Minnesota,
USA; Megazyme, Australia; Technical University of Berlin, Germany; ConAgra, Nebraska,
USA; Grain Research Laboratories, Winnipeg, Canada; NSW Agriculture, Sydney, Australia;
and Bread Research Institute, Sydney, Australia.

Table 1. Inter-laboratory evaluation of two methods for ß-glucan determination, AACC 32-22 ("AACC") and Megazyme ("Mega") streamlined procedures (% dry basis).

(a) Raw data

Sample:	A		B		C		D		E	
Method:	AACC	Mega	AACC	Mega	AACC	Mega	AACC	Mega	AACC	Mega
Lab. No.										
1	2.52	2.13	5.80	5.35	4.11	4.09	4.28	4.57	2.56	2.53
2	2.18	2.71	5.82	6.27	4.03	4.13	4.13	4.30	2.58	3.03
3	3.32	2.80	6.89	6.93	4.69	3.94	5.01	4.71	3.35	3.12
4	2.14	2.49	6.25	6.12	4.06	3.63	3.98	3.61	2.37	2.67
5	3.00	2.90	6.30	6.20	4.50	4.20	4.90	4.40	3.30	3.00
6	2.11	2.66	5.90	6.97	3.61	4.03	3.79	3.62	2.59	3.12
7	3.03	2.53	6.46	6.27	4.60	3.94	4.52	4.01	3.44	3.05
8	2.48	2.42	6.21	5.94	3.99	3.94	4.62	4.28	2.85	2.73
Mean:	2.60	2.58	6.20	6.26	4.20	3.99	4.40	4.19	2.88	2.91

Sample:	F		G		H		I		J	
Method:	AACC	Mega	AACC	Mega	AACC	Mega	AACC	Mega	AACC	Mega
Lab. No.										
1	5.71	6.35	7.70	8.86	4.07	3.95	7.00	7.16	4.36	2.76
2	6.21	6.46	7.98	8.45	4.03	4.49	7.73	7.44	3.94	4.01
3	7.98	6.96	8.70	9.27	4.41	4.52	8.52	8.55	4.16	4.45
4	5.95	5.94	8.20	7.90	3.63	4.01	7.74	7.18	3.77	3.76
5	7.60	6.99	8.91	9.00	4.80	4.50	8.50	7.00	4.90	4.00
6	6.22	7.25	7.23	8.51	3.88	4.42	6.54	8.54	4.19	4.14
7	7.15	6.94	9.21	8.73	4.91	3.91	8.71	7.82	4.39	4.38
8	6.48	6.43	8.66	8.12	4.60	4.27	7.88	7.45	4.30	4.20
Mean:	6.66	6.67	8.32	8.61	4.29	4.26	7.83	7.64	4.25	3.96

(b) Statistical analysis

Sample pair	AACC method 32-22*					Megazyme streamlined method*				
	Mean	s_r	s_R	RSD_r	RSD_R	Mean	s_r	s_R	RSD_r	RSD_R
AE	2.74	0.120	0.444	4.4	16.2	2.74	0.098	0.236	3.6	8.6
BF	6.43	0.387	0.635	6.0	9.9	6.46	0.283	0.481	4.4	7.4
HD	4.35	0.208	0.447	4.8	10.3	4.22	0.297	0.344	7.0	8.1
JC	4.23	0.274	0.352	6.5	9.3	3.98	0.411	0.397	10.3	10.0
GI	8.08	0.153	0.716	1.9	8.9	8.12	0.448	0.537	5.5	6.6

* n = 8 (8 participating laboratories), no outliers were detected by Cochran or Grubbs tests
s_r = repeatability standard deviation (within laboratories)
RSD_r = repeatability Relative Standard Deviation (%)
s_R = reproducibility standard deviation (between laboratories)
RSD_R = reproducibility Relative Standard Deviation (%)

The data in Table 1 was evaluated according to AS2850-1986, based on ISO 5725.

Results and Discussion

ß-Glucan values on a dry weight basis, and the statistical evaluation of this data is shown in Table 1. No significant difference was found between the ß-glucan results of the two methods (p>0.05). There also appeared to be little difference in precision between the two methods. The regression equation is:

$$\text{Megazyme (ß-glucan)} = -0.219 + 1.031 \text{ (AACC) (n= 10, Average data)}$$
$$\text{(correlation coefficient} = 0.997).$$

In evaluating samples for inclusion in this study, we performed a detailed study on the effect of continuous stirring and incubation time during the lichenase step, and the effect of longer cooking time in the pre-lichenase treatment step. These studies were performed on a commercial oat bran sample which had a very high ß-glucan content. The results of this study are shown in Table 2. It is evident that each of the variations gave essentially the same results. However, because one of the replicates with the 20 min lichenase treatment gave a lower value than with the other procedures, we have decided in our standard procedure to increase the time of incubation to 60 min (as used in the original format).

Table 2. Measurement of ß-glucan in oat fibre; effect of extraction and incubation conditions.

Sample	Cooking Time (at 100°C)	Lichenase Treatment Incub. Time	Stirring	Beta-Glucan (% w/w)
A	1 + 2	20 min	NO	8.4, 8.8
B	1 + 2 + 2	20 min	NO	8.7, 8.9
C	1 + 2 + 2	20 min	YES	8.9, 8.8
D	1 + 2	60 min	NO	8.9, 9.0
E	1 + 2	90 min	NO	8.9, 8.9
F	1 + 2	20 min	YES	8.8, 9.0
G	1 + 2	60 min	YES	8.7, 9.0

Cooking was performed in a boiling water bath. Tubes and contents were stirred vigorously on a vortex mixer immediately after addition of the buffer;

after 1 min incubation in the boiling water bath;
after a further 2 min incubation, and, in some cases,
after a further 2 min incubation at 100°C.

Incubation and stirring were performed in the "Multistir Incubation Bath" throughout the entire incubation time where the word "YES" appears. Where the word "NO" appears, the tubes were incubated at 50°C, and stirred occasionally during the incubation period using a vortex mixer.

References

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4. **McCleary, B.V. and Codd, R.** 1991. *J. Sci. Food. Agric.* 55. 303-312.