SCOTTISH PLANT BREEDING STATION

REPORT

April 1978 to March 1979

And the Report to the fifty-eighth
Annual General Meeting of the

SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING

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STAFF LIST

(In post 31st March 1979)

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Brassica Department

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Experimental Worker: A. R. Whitelaw

Photography:

Photographer: Miss G. Cruickshank

POTATO DIVISION

Head: J. H. W. Holden, B.Sc., Ph.D.

Commercial Breeding Department

PSO: T. M. W. Davidson, B.Sc., Ph.D., N.D.A. (Head)
G. R. Mackay, M.Sc.

SSO: R. J. Killick, B.Sc., Ph.D., M.I.Biol.

HSO: Mrs R. M. Hine, B.Sc., C. J. W. Torrance, H.N.C.

ASO: Miss M. E. Pearce, Mrs J. S. Spence, G. E. L. Swan

Experimental Workers: M. P. L. Campbell, Mrs M. M. S. Dugan, L. G. Robertson

Pathology Department

PSO: R. L. Wastie, M.A., Ph.D., F.I.S.P. (Head)

SSO: J. M. S. Forrest, B.Sc., Ph.D.

HSO: M. S. Phillips, B.Sc., Miss R. M. Solomon, B.A., M.Sc.,
Miss H. E. Stewart, H.N.C., M.I.Biol.

SO: Miss I. B. Majewicz, B.A., Miss L. A. Wilson, H.N.D., L.I.Biol.

ASO: Miss F. Mathison, O.N.C.

Experimental Worker: Mrs E. M. Wann

Strategic Breeding Department

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SSO: C. P. Carroll, M.Sc.

HSO: M. J. De, Maine, B.Sc.

ASO: Miss D. L. Harris, Miss S. Milligan

Cytology Unit

HSO: Mrs J. A. Fantes, M.A.

ASO: A. C. Wilkinson

DIRECTOR'S REPORT

R. C. F. MACER

In July 1978 Her Majesty's Secretary of State for Scotland set up a Working Party to review the future requirements for state-funded plant breeding and crop research in Scotland. The full remit of the Working Party was to:—

a. examine the present arrangements for the commissioning and organisation of research on horticulture, plant breeding and arable crop production at the Scottish Plant Breeding Station (SPBS) and the Scottish Horticultural Research Institute (SHRI);
b. consult the Governing Bodies, Directors and Senior Scientific Management of the two Institutes and the trade unions concerned;
c. take into account views submitted by bodies representative of Scottish agriculture or Scottish horticulture;
d. consider in the light of consultations and examination of the current situation and of the views submitted whether any changes are necessary either in relation to the horticulture, plant breeding, and arable crop production research commissioned by the Secretary of State for Scotland at the two Institutes or the organisational structure for carrying out that research with a view to obtaining the optimum results for the benefit of the agricultural and horticultural industry; and
e. to report.

The members of the Working Party were:—

Mr W. W. Gauld, Under Secretary, Department of Agriculture and Fisheries for Scotland (DAFS) Chairman
Mr John Arbuckle, O.B.E., Chairman of Board of Directors, Scottish Society for Research in Plant Breeding (SSRPB)
Mr W. A. Biggar, O.B.E., M.C., F.R.Ag.S., Trustee of the SSRPB
Professor Sir Kenneth Mather, C.B.E., F.R.S., Department of Genetics, University of Birmingham
Mr A. Gordon Porter, J.P., Chairman, Board of Governors, SHRI
Professor N. F. Robertson, C.B.E., F.R.S.E., Principal, East of Scotland College of Agriculture.

The need for a balanced and well-found programme of research on crops used in a northerly cool-temperate climate is undisputed. The establishment of the Working Party was welcomed by the Board of the Society and by the staff at the Station. It was recognised that any recommendations made by the Working Party could have fundamental consequences for the future of the Station, the staff, and for the Society. Substantial capital investment is now needed to provide facilities for modern plant breeding programmes and

ancillary research to be conducted into the twenty-first century. Plant breeding is, by its very nature, a long-term facet of agricultural research and decisions taken now will strongly influence all future research programmes.

A considerable amount of time has been devoted by staff, acting as individuals and in groups, to collecting and presenting information and views to the Working Party before, during and since the period of its deliberations in October and November 1978. The Working Party was received at the Station on 4th and 5th October, 1978. The recommendations of the Working Party were made known to staff in December. In summary, these were that the level of crop research in Scotland should be maintained and, if possible, increased but that it would best be carried out in a new institute formed from an amalgamation of the SPBS and the Scottish Horticultural Research Institute on an extended site at Dundee. The Board of SSRPB has met monthly during the winter to keep the position under review. The Secretary of State for Scotland has asked for responses to these recommendations and, at the end of the year under review, the recommendations and the responses to them are still being considered by him.

A study of this type and the profound nature of the recommendations has, therefore, dominated the activities of the Station for most of the year. Consequential administrative action resulting in the freezing of capital building projects and in the delay in filling staff vacancies has caused some disruption to the research programme. Nevertheless, most research projects have advanced and it is to be hoped that the period of uncertainty about the future of the Station will be resolved early in the next financial year.

The Station's research programme, which is fully commissioned by the Department of Agriculture and Fisheries for Scotland, is now based upon the revised 'packages' and 'projects' introduced on 1st April, 1978. These are listed in full on pages 142-5.

The Experimental Station at the Murrays, near Pathhead, has been improved further during the year. The major and extensive re-drainage operations have been completed and the expected benefits obtained. Road-building and re-fencing was continued. A long-term rotational programme to improve soil structure and fertility and to maintain freedom from the major soil-borne pests and diseases is now in operation. The 1978 potato trials were the first to be grown on re-drained land and in 1979 the trials of all three major crops will be grown on land drained in the 1977 programme.

Four potato varieties, two barley varieties and two swede varieties have been submitted for NLT trials in 1979; the details of these varieties are given later in the report. There now appears to be every possibility that submissions representing our major crops can be made regularly in future years. Pentland Squire, an early maincrop potato, was added to the Provisional Recommended Lists of the NIAB in 1978 but the variety Croft was removed from the NIAB Recommended List and Craigs Alliance, Craigs Royal and Red Craigs Royal were transferred from the general to the out-classed category.

In the last two Annual Reports the review articles were devoted to aspects of the Station's potato and brassica breeding programme. The cereals form the Station's third major breeding endeavour and the review article this year is written by Dr M. J. Allison, Dr R. P. Ellis, Dr A. M. Hayter and Mr J. S. Swanston; it covers the important areas of breeding and testing for quality in barley. Quality aspects of breeding programmes are becoming increasingly important and nowhere is this more important than in the barley crop, especially in Scotland. This review article also demonstrates the increasing importance of inter-disciplinary approaches in plant breeding and shows the close collaboration that now takes place between the Cereals and Chemistry Departments.

The Secretary and Treasurer of the Society and Station Secretary, Mr H. C. M. McLeod, resigned in November 1978 to take up an appointment as Secretary of our neighbouring institute, the Hill Farming Research Organisation. Mr McLeod joined the staff of the Scottish Plant Breeding Station as Assistant Secretary in 1972 and took up his Secretary and Treasurer appointments in 1974. His period of office was a busy and eventful time for the Station and he played an active and important part in all the developments that took place. We wish him well in his new post.

We welcome Mr J. R. Love who took up the post of Secretary and Treasurer of the Society and Station Secretary on 1st March, 1979.

I should once again like to thank Dr F. J. W. England and his colleagues on the Editorial Committee who have edited this Report and who have seen it through the press.

INFORMATION CONCERNING STAFF AND VISITORS

Director

Dr R. C. F. Macer continued to serve as a member of the JCO Arable Crops and Forage Board and as Chairman of its Cereals Committee. He also continued to serve on the Selection Panel of the Scientific Awards Advisory Committee of the Royal Agricultural Society of England, as a member of the ARC/BAPB Joint Consultative Committee, as a member of the NSDO Advisory Committee and as a member of the board and committee member of the Edinburgh Centre for Rural Economy.

He acted as External Examiner for the Department of Genetics of the University of Birmingham and continued to act as External Examiner in the Departments of Agricultural Genetics and Agricultural Botany of Queen's University, Belfast, Northern Ireland.

Staff

Mr J. Currie, Mr A. Knox and Mr M. McPartlan retired as agricultural workers in the Agronomy Department.

New appointments during the year included: Mr J. R. Love (Higher Executive Officer); Mr J. W. McNicol (Higher Scientific Officer); Miss I. B. Majewicz (Scientific Officer); Mr T. Nelson and Mr G. W. Swinney (Assistant Scientific Officers); Mrs E. P. Pendreich (Clerical Officer); Mrs J. I. Gordon (Experimental Worker III); Mr L. W. Fenty (Experimental Worker V); Mr W. Cherrie (Storekeeper); Mr D. L. Magrath (Craftsman Engineer); Mr W. I. S. Harrower (Handyman's Assistant); Mr J. M. Fairley, Mr C. I. Young and Mr W. Russell (Agricultural Workers).

Resignations included: Mr H. C. M. McLeod who left the post of Secretary at SPBS to join HFRO; Mr P. N. Easson and Mrs L. E. Gray (Scientific Officers), Mr D. A. B. Brown, Miss J. A. Galbraith, Mr P. W. Gettings, Mr R. S. Hird, Miss J. G. Queen, and Mr J. A. Scott (Assistant Scientific Officers); Miss D. Trench (Clerical Officer); Miss S. A. Byiers (Experimental Worker); Mr R. G. Gray (Storeman); Mr G. Stevens (Craftsman) and Mr R. Simpson (Agricultural Worker).

Promotions included Mr M. J. De, Maine to Higher Scientific Officer; Mr R. H. McHale to Scientific Officer; Miss G. Cruickshank to Photographer, and Miss L. S. MacPherson and Mr L. G. Robertson to Experimental Worker I.

Visitors

There were a number of visitors from ARC Headquarters, including Mr D. C. M. Corbett, ARC adviser in plant pathology; Dr G. Price who discussed ARC2 and JAR reporting with staff; and Dr J. Ingle accompanied by Mr J. G. Brotherston of DAFS, who reviewed progress with infra-red reflectance methods at SPBS; and Dr J. D. Hayes, ARC adviser in plant breeding.

Other visitors to the station during the year included Professor J. P. Cooper, F.R.S., Director WPBS, Aberystwyth to deliver the Eighth SSRPB Lecture (*Ann. Rep. 1977-78,* 126-134); Mr J. S. Denton of Nickersons Seed Co. Ltd., to discuss data-processing and mechanisation; Dr C. A. Huijsman of Wageningen and Drs van der Wal and de Scurrah of the International Potato Centre, Lima, Peru to discuss breeding for resistance to potato eelworm; Professor J. Sneep of Wageningen to see the work of SPBS and to discuss the possibilities for collaboration in higher education; Mr A. F. Visser, Head of Potato Breeding, at the South African National Potato Centre to see the work of the Potato Division; Dr T. Shiga of the National Institute of Agricultural Science, Hiratska and Dr H. Namai of the Institute of Agriculture and Forestry, University of Tsukuba, Ibaraki, Japan to discuss the work of the Brassica Department; Dr Harvey C. Smith of DSIR Crop Research Division, New Zealand to discuss collaboration between the SPBS Cereal and Brassica Departments and DSIR at Gore, New Zealand; Mr P. Ridge of the Department of Agriculture, Victoria, Australia to discuss cereal breeding; Dr R. Kessel of the Volcani Institute, Israel to discuss various aspects of the use and conservation of potato germ-plasm; Professor G. Milbourn and Dr G. Russell of the School of Agriculture, Edinburgh University to discuss collaboration with cereal breeders on physiological studies; Dr L. Sikka to discuss collaboration between potato breeders at SPBS and in Kenya; a visit from Dr A. Andrásfalvy of the Research Institute for Vegetable Crops, Budapest, Hungary to see various aspects of SPBS work; Professor N. L. Innes and colleagues of the NVRS, Wellesbourne to discuss Brassica physiology; Mr Lars Eskilsson of Weibullsholm, Sweden to discuss cereal breeding, particularly oats; Dr R. F. Curtis and colleagues from the FRI, Norwich to discuss potato quality; Dr R. E. Gaunt of Lincoln College, New Zealand to discuss cereal pathology and physiology; Mr M. F. Collins and Mr D. Mason of Rothwell Plant Breeders to see cereal trials at the Murrays; Mr W. E. Lloyd-Green of Bathurst, New South Wales, Australia to discuss canning potatoes and Mr S. V. Petherick of Queensland Agricultural College, Australia, to study the work of the SPBS in general.

There were visits from several groups including a number of visits from NSDO personnel to discuss Brassicas, Potatoes, Cereals and marketing arrangements; a party from the conference of the Federation of European Societies of Plant Physiologists to see demonstrations of various aspects of SPBS work; a party from the Seed Technology Course of the Crop Hus-

bandry Department, School of Agriculture, Edinburgh University; and a party from J. E. England and Sons, Abernethy on a fact-finding visit to the Potato Division. In addition, members of staff demonstrated various aspects of SPBS work to parties of university students from the Department of Genetics, Aberdeen; the Department of Botany, St. Andrews; the Department of Botany, Edinburgh; the Edinburgh School of Agriculture; the Department of Agriculture, Aberdeen; and the Department of Agriculture, Leeds.

Visits abroad

Dr F. J. W. England visited Libya as consultant to an FAO/Libyan government project collecting forage legume species.

Dr M. J. C. Asher attended the Third International Congress of Plant Pathology in Munich and presented a paper on "Hypovirulence in populations of *Gaeumannomyces graminis* var *tritici*. He also visited research stations in Wageningen to study research on cereal diseases.

Mr I. A. Cowe visited the United States to survey progress with infra-red reflectance analysis and malting quality.

Dr I. H. McNaughton visited the DSIR, Gore, New Zealand to liaise and advise on brassica breeding and allied research. Mr R. N. H. Whitehouse returned from Gore in April, 1978 and Dr W. T. B. Thomas left in January, 1979 to select and harvest this year's SPBS barley breeding material.

Dr J. H. W. Holden visited potato trial sites in Valencia, Spain and La Puebla, Majorca. He also attended the EPPO conference "Breakthroughs in resistance breeding" and visited potato breeders in Norway and Sweden.

Mr G. R. Mackay and Mrs R. M. Hine visited Holland and Germany to study potato breeding and research.

Dr R. J. Killick, Mr M. J. De, Maine and Miss R. M. Solomon attended the Seventh Triennial Conference of the European Association for Potato Research in Warsaw, Poland. Dr Killick presented a paper entitled "Combining abilities in potatoes", and a second paper on behalf of Dr J. M. S. Forrest and Mrs R. M. Hine entitled "Screening for resistance to the white potato cyst nematode". Mr De, Maine delivered a paper on "A new approach to the use of dihaploids in breeding for increased pathogen resistance in potatoes". Miss Solomon presented a paper on "Methods of screening for resistance to potato viruses X and Y", and a second paper on behalf of Dr R. L. Wastie and Miss H. E. Stewart entitled "Field and glasshouse assessment of resistance to late blight". Miss Solomon also visited a number of plant breeding and research stations in Poland.

Dr R. L. Wastie visited Brazil to advise the Centro Nacional de Pesquisa da Seringueira at Manaus on research on diseases of *Hevea* rubber.

Mr D. R. Glendinning attended a conference on "Broadening the Genetic Base of Crops" at Wageningen and presented two papers entitled "Enriching the potato gene-pool using primitive cultivars" and "The potato gene pool,

and benefits deriving from its supplementation." He also attended a colloquium on gene-banks at Braunschweig, West Germany.

Dr A. M. Hayter visited the Risø National Laboratory in Denmark to learn the techniques of haploid production using *Hordeum bulbosum*. He also gave a seminar entitled "Cereal breeding at the Scottish Plant Breeding Station" and talked to barley research workers at Risø, the Carlsberg Research Laboratories, and the Copenhagen Veterinary and Agricultural University in Denmark, and Weibullsholm and Svalöf in Sweden.

Visits, Conferences and Lectures within the UK

Dr J. H. W. Holden attended the NSDO annual advisory meeting with ARS Directors, representing the Director, Dr Macer.

Mr R. N. H. Whitehouse, Drs M. J. Allison, M. J. C. Asher, R. P. Ellis, W. T. B. Thomas, and Mr J. S. Swanston attended the ARS Cereal Breeders meeting at the PBI, Cambridge.

Drs J. H. W. Holden, M. J. C. Asher, R. L. Wastie and C. J. Williamson attended the AAB meeting "Variation in plant pathogens" at the University of East Anglia, Norwich. Dr Asher was co-author of a paper entitled "Inheritance of pathogenicity in the take-all fungus" delivered by Dr P. Blanch.

Members of staff made a number of visits to sister institutes in the ARS and to other centres. These included Dr J. F. Malcolmson to Long Ashton Research Station to learn techniques in scanning electron microscopy; Dr R. P. Ellis to the Guinness Research Station, Warminster and to Bangor for a meeting of the Phytochemical Society where he demonstrated research on breeding for tolerance of low pH in spring barley; Drs Ellis and W. T. B. Thomas to the National Agricultural Centre for a conference on winter barley; Dr M. J. Allison to the Flour Milling and Baking Research Institute, Chorleywood, with Mr I. A. Cowe to the PBI, Cambridge to discuss the work of the Chemistry Departments, and with Dr I. H. McNaughton to the Rowett Research Institute, Aberdeen to discuss toxic factors in brassicas, particularly SMCO; Dr J. E. Bradshaw to ADAS Starcross, Exeter, and Seale Hayne on a fact finding visit of an important kale growing region; Dr C. J. Williamson to NVRS, Wellesbourne; Drs J. H. W. Holden and T. M. W. Davidson visited a number of centres in connection with potato breeding and research; Mr C. J. W. Torrance to the NIAB and PBI, Cambridge to discuss potato cooking quality; Dr J. M. S. Forrest, Mr M. S. Phillips and Miss Linda A. Wilson to a number of centres in connection with potato nematology and Miss I. B. Majewicz to a number of centres in connection with various aspects of potato virology.

Many members of staff gave lectures to external bodies; these included Mr R. N. H. Whitehouse on "Cereal breeding" in the Biology Department of Stirling University and on "Barley breeding" to the Scottish Seed Growers Association; Dr R. P. Ellis on "Cereal breeding" to M.Sc. Seed Technology students of the Crop Husbandry Department of the School of Agriculture.

Edinburgh University; Mr R. J. Giles on "Cereal collections at the SPBS" and Mr D. R. Glendinning on "The Commonwealth Potato Collection" to students of the IBPGR sponsored training course also at the Crop Husbandry Department of Edinburgh University; Dr J. H. W. Holden on "Potato breeding at Pentlandfield" to a meeting of overseas potato merchants; Mr G. R. Mackay on "New rapes for old" to the Botany Department, St. Andrews University and on "Incompatibility and its use in the improvement of brassica crops by plant breeders" to the Botany Department of Edinburgh University.

Mr D. W. Speed attended a meeting of ARS Safety Officers at ARC Headquarters and Miss Geraldine Cruickshank took part in the ARS Photographers Seminar at the Rowett Research Institute, Aberdeen.

Seminars

The winter seminar programme included seminars by Professor S. Desborough, University of Minnesota, U.S.A., on "Protein studies in *Solanum*"; Mrs R. M. Hine and Mr G. R. Mackay (SPBS) on "Potato breeding and research in the Netherlands"; Mr I. A. Cowe (SPBS) on "Infra-red absorption analysis in the service of plant breeding"; Mr J. Thomson of the Biology Department of Stirling University on "The physiology of ear development in barley"; Mr K. V. Runcie (ESCA) on "What Scotland wants from crop breeding"; Mr J. McFarlane (SSRPB) on "The farmers future requirements in potatoes" and Mr M. J. De, Maine (SPBS) on "Pollen storage".

Membership of committees

Mr R. N. H. Whitehouse served as a member of an ARC promotion panel and continued to act as co-editor of the *Eucarpia, Cruciferae Newsletter*. He continued as Chairman of the local organising committee of the Fourth International Barley Genetics Symposium, which will be held in Edinburgh in 1981, and several staff members continued to act as committee members. Mr Whitehouse also served as a member of the International Organising Committee.

Dr J. F. Malcolmson continued to serve on the Scottish Joint Committee for National Certificates and Diplomas in Biology and on sub-committee E (Infraspecific) of the International Mycological Association.

Dr J. H. W. Holden served as a member of the JCO Potatoes Committee. He and Dr W. H. MacFarlane Smith served as members of the National Proficiency Test Council.

Dr F. J. W. England continued to act as convener of the plant breeding group of the AAB, and became co-ordinator for the BAPB/ARC spring barley trials for 1979.

Dr J. M. S. Forrest served on the Nematology Group Committee of the AAB and as a member of the ADAS Potato Nematode working party.

Courses attended

A number of staff attended courses on ARC JAR interviewing, ARC new entrants courses, SRC/ARC management courses, courses for occasional speakers, paper writing, glasshouse management, Fortran programming and other computer courses at ERCC, and day-release courses leading to City and Guilds, ONC and HNC qualifications.

Mr R. N. H. Whitehouse attended a SRC course on selection and promotion interviewing.

Dr J. F. Malcolmson attended a Royal Microscopical Society course on scanning electron microscopy and an ARC course on advanced recording techniques.

Mr R. Borzucki attended a Pharmacia course on column chromatography and gel filtration.

Dr J. M. S. Forrest learned tissue culturing techniques in the Botany Department of Edinburgh University.

A number of staff also attended courses of technical instruction including Mr D. L. Magrath on general maintenance welding, Mr H. B. Jamieson on fork lift truck driving, Mr T. Gifford on meteorology, Mr D. Ritchie on farm records and accounts, Mr R. G. Tait on workshop practice and Mr L. G. Robertson on potato roguing.

New Qualifications

Mrs D. J. Barclay passed Part I of the Licentiate of the Institute of Biology. Mr J. Brown gained his HNC in Mathematics, Statistics and Computing and Mr R. H. McHale his HNC in Biology. Miss S. Milligan and Mr G. Swinney obtained ONC in biology and Mr J. G. McClusky obtained 'O' level passes in Chemistry, Mathematics and Biology. A number of staff including Miss F. Mathison, Miss J. E. Middlefell, Miss D. A. Page, Miss E. A. Young, Miss C. E. Anderson, Miss C. M. McParland, and Mr A. C. Wilkinson passed intermediate examinations leading to ONC and HNC qualifications. Miss G. Cruickshank passed the intermediate City and Guilds examination in Photography. Mr D. Ritchie and Mr G. Tait both obtained the Craftsman Certificate of the Agricultural Training Board.

Subsequent promotions

Dr R. J. Killick was promoted to Principal Scientific Officer and Miss Frances M. Bruce, Mr J. Brown and Mr G. E. L. Swan were promoted to Scientific Officers from 1st April, 1979.

International Symposium

The Fourth International Barley Genetics Symposium will be held in Edinburgh from 22nd to 29th July 1981. The Centre for Industrial Con-

sultancy and Liaison, University of Edinburgh, 16 George Square, Edinburgh has been engaged to organise the Symposium and all enquiries should be addressed to Mr W. Campbell. Mr R. N. H. Whitehouse is a member of the Symposium General Organising Committee which comprises nine international members. H.R.H. The Duke of Edinburgh has agreed to act as Symposium Patron. The Advisory Committee, representing agricultural research, industrial and other interests in the Edinburgh area, met for the first time at SPBS on 18th May, 1978. Members of staff are serving on the local Executive Committee and sub-committees.

COLLABORATORS

This list of collaborators in the work of the Station includes farmers, landowners, colleges and official organisations who have provided field facilities, and workers in universities and official and industrial laboratories who have provided valuable scientific help. We hope that the list is complete, and to all collaborators, named or (perchance) unnamed, we offer our best thanks.

(a) Agricultural Research Council Institutes

There has been direct collaboration during the year with the fourteen ARC and State-aided Institutes marked with asterisks in the list on pp 146–7.

(b) Other official bodies

Agricultural Development and Advisory Service at Bangor, Cambridge and Newcastle; at Gleadthorpe, Terrington and Arthur Rickwood Experimental Husbandry Farms; and at Rosewarne Experimental Horticulture Station.

Department of Agriculture and Fisheries for Scotland, Scientific Services, Edinburgh.

Department of Scientific and Industrial Research, Crop Research Division, New Zealand.

Edinburgh Centre of Rural Economy.

Forestry Commission, Research Branch, Edinburgh.

National Institute of Agricultural Botany, Cambridge, Cockle Park and Headley Hall.

National Seed Development Organisation, Cambridge.

Potato Marketing Board, London.

Royal Botanic Garden, Edinburgh.

Swedish Seed Association, Svalöf.

(c) Universities and Colleges

Agricultural Research Council Unit of Statistics, Edinburgh University.

Birmingham University, Department of Genetics.

East of Scotland College of Agriculture, Edinburgh.

Edinburgh Regional Computing Centre.

Edinburgh University, School of Agriculture and Department of Botany.

Heriot-Watt University, Department of Brewing and Chemistry.

Newcastle upon Tyne University, School of Agriculture.

North of Scotland College of Agriculture, Aberdeen.
Stirling University, Department of Biology.
University College of Wales, Aberystwyth.
West of Scotland College of Agriculture, Ayr.

(d) Industrial Collaborators

American Calan Inc., Route 4, Northwood, New Hampshire, U.S.A.
Borax Consolidated Limited, Borax House, Carlisle Place, London.
Brewing Research Foundation, Redhill, Surrey.
British Association of Plant Breeders, Ely, Cambridgeshire.
Cadbury-Typhoo, Ltd., Richmond, Yorks.
Calan Electronics Ltd., near Ormiston, East Lothian.
Dalgety Agricultural Research, Timaru, New Zealand.
Dornay Foods Ltd., Kings Lynn, Norfolk.
East Coast Viners Grain, Ltd., Drumlithie, Stonehaven, Aberdeenshire.
J. E. England and Sons (Wellington) Ltd., Perthshire.
Flour Baking and Milling Research Foundation, Chorleywood, Herts.
Fridlington Farms Ltd., Plantation Farms, Sheriff Hutton, Yorks.
Golden Wonder Ltd., Broxburn, W. Lothian.
H. J. Heinz Co. Ltd., Hayes Park, Hayes, Middlesex.
McCain International Ltd., Scarborough, Yorks.
Miln Marsters Group, Chester.
Moray Firth Maltings, Inverness.
Pauls and Sanders Ltd., Key Street, Ipswich, Suffolk.
Pentlands Scotch Whisky Research Ltd., Edinburgh.
Potato Processors Association, Eastham, Grantham, Lincs.
Rahr Malting Co. Inc., Shakopee, Minneapolis, Minnesota, U.S.A.
Ross Produce Ltd., Peterborough, Northants.
Rothwell Plant Breeders Ltd., Lincs.
Scottish Agricultural Industries Ltd., Edinburgh.
Sinclair McGill (Scotland) Ltd., Ayr.
Smiths Food Group, Grantham, Lincs.

(e) Individuals

J. Black, Drochil Castle, Peeblesshire.
J. Craigs, Trithington Hall, Trithington, Northumberland.
T. Dale, Scoughall, North Berwick, East Lothian.
V. Evans, Bubbleton, Penally, Dyfed.
G. Finlay, Shanwell Farm, Tayport, Fife.
J. Barclay Forrest, Whitemire, Duns, Berwickshire.
A. Gordon, Balmuchy, Fearn, Ross and Cromarty.
J. S. Graham, Queenstonbank, East Lothian.
E. Jones, Lunnon Farm, Lunnon, Swansea.

A. Lewis, Cefn Ceido, Rhayader, Radnor.
J. F. MacBrayne, West Byres, Ormiston, E. Lothian.
W. McCrone, Cairnside, Kirkcolm, Stranraer, Wigtown.
J. MacFarlane, Flichity Farm, Farr, Inverness.
I. K. MacKenzie, Inverarnie, Farr, Inverness.
R. Miller, Tullochgorum, Inverness-shire.
A. G. Porter, East Scryne, Carnoustie, Angus.
W. H. Porter, West Scryne, Carnoustie, Angus.
J. Riddell, West Peaston Farm, Ormiston, E. Lothian.
R. G. Robinson, Christchurch, New Zealand.
T. Rowe and Sons, Over Ardoch, Braco, Perthshire.
G. A. Storrar, Rossie, Auchtermuchty, Fife.
R. Trotter, Ormiston Mains, Ormiston, E. Lothian.
A. B. Turnbull, Home Farm, Penrice, Glamorgan.

LIST OF ABBREVIATIONS

Organisations:

AAB	Association of Applied Biologists.
ADAS	Agricultural Development and Advisory Service.
ARC	Agricultural Research Council.
ARCUS	Agricultural Research Council, Unit of Statistics.
ASCAR	Anglo Soviet Co-operation for Agricultural Research.
BAPB	British Association of Plant Breeders.
DAFS	Department of Agriculture and Fisheries for Scotland.
DSIR	Department of Scientific and Industrial Research (New Zealand).
EAPR	European Association for Potato Research.
ECRE	Edinburgh Centre of Rural Economy.
EHF	Experimental Husbandry Farm.
ERCC	Edinburgh Regional Computing Centre.
ESCA	East of Scotland College of Agriculture.
FBPP	Federation of British Plant Pathologists.
FRI	Food Research Institute.
GRI	Grassland Research Institute.
HFRO	Hill Farming Research Organisation.
IBPGR	International Board for Plant Genetic Resources.
JCO	Joint Consultative Organisation.
MAFF	Ministry of Agriculture, Fisheries and Food.
NIAB	National Institute of Agricultural Botany.
NoSCA	North of Scotland College of Agriculture.
NSDO	National Seed Development Organisation.
NVRS	National Vegetable Research Station.
PBI	Plant Breeding Institute (Cambridge).
RES	Rothamsted Experimental Station.
RoSPA	Royal Society for the Prevention of Accidents.
RRI	Rowett Research Institute.
SARI	Scottish Agricultural Research Institutes.
SHRI	Scottish Horticultural Research Institute.
SPBS	Scottish Plant Breeding Station.
SSRPB	Scottish Society for Research in Plant Breeding.
UCW	University College of Wales.
WPBS	Welsh Plant Breeding Station.
WSCA	West of Scotland College of Agriculture.

Others

APZ	Code-name of an SPBS swede breeding line.

CASE	Co-operative Awards in Science and Engineering.
CPC	Commonwealth Potato Collection.
CVT	Co-ordinated Variety Trials and also the computer program which designs and analyses them.
DIALOG	An interactive information retrieval computer language developed by Lockheed Research Laboratory, Palo, Alto, California.
DOMD	Digestible Organic Matter in the Dry Weight.
DUS	Distinctness Uniformity Stability.
ECD	European Club-root Differential.
EDEX	Edinburgh Experiments program.
EMAS	Edinburgh Multiple Access (Computer) System.
EMS	Ethyl methane sulphonate.
EXIR	Executive Information Retrieval program.
JAR	Job Appraisal Review.
NLT	National List Trials.
NUMAC	Northumbrian Universities Multiple Access Computer.
PCN	Potato cyst nematode.
PMC	Pollen mother cell.
PMTV	Potato mop-top virus.
PSTV	Potato Spindle Tuber Virus.
PVR	Plant Variety Rights.
RLT	Recommended List Trials.
SMCO	S-Methyl cysteine sulphoxide.
TCA	Trichloracetate.
TRV	Tobacco rattle virus.
VTSC	Virus Tested Stem Cutting.

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FORAGE DIVISION

Barley Genetics

Trials to investigate the suitability of small-scale tests for the prediction of hot water extract were completed and indicated the value of the milling energy test. Physiological studies on four varieties continued, in collaboration with PBI. Investigations of nitrate reductase were begun. In collaboration with the University of Birmingham, assessments were made on the progenies of five triple test crosses to enable predictions to be made of the expected gains from selection, for comparison with the realised gains from selection, to be estimated from the performance of selected and unselected material from the original five pair crosses, which will be assessed in 1979 and 1980. Attempts to assign major dwarfing genes to particular linkage groups continued.

Investigations of small-scale tests for predicting malting quality (*Ann. Rep. 1975-76,* 7; *1976-77,* 19 and *1977-78,* 23) have been completed and the data prepared for formal publication. The milling energy test, developed by the Chemistry Department, showed considerable potential for the prediction of malting quality. Using multiple regression, the most accurate prediction of hot water extract was obtained from grinding resistance (similar to milling energy), grain nitrogen content and alpha-amylase activity. The fitted regression of hot water extract in brewers pounds per quarter (y) against grinding resistance (x_1), grain nitrogen (x_2) and alpha-amylase (x_3) was

$$y = 126 - 0{\cdot}22x_1 - 16{\cdot}42x_2 + 0{\cdot}02x_3$$

which accounted for 65 per cent of the variance of y.

The estimation of alpha-amylase is the only test which requires germination of the grain samples. The results indicate a close relationship between malting quality and both the physical composition and the germinative properties of the grain.

The collaborative physiological studies with Dr E. J. M. Kirby of the PBI (*Ann. Rep. 1976-77,* 19 and *1977-78,* 23) were completed and the data on apical development are being prepared for publication. In 1978 these studies were assisted by Miss Shona McFarlane, a sandwich student from Dundee College of Technology, who spent six months in the Cereals Department. Apical development was observed in Golden Promise, Maris Mink, Clipper and Tyra. The experimental plots were sown later, in 1978, than in the preceding years due to cold wet weather in March. This was followed by a dry period just after the start of stem elongation and resulted in shorter than average plants. Clipper reached maximum primordium number more rapidly than did the other varieties and produced fewer grains per ear. Mature

plants were harvested intact from all plots and the components of yield are being studied in detail. Eventually it is hoped that optimum patterns of apical primordium development can be defined, assisting plant breeders in the formulation of breeding models.

The investigations on the value of cross prediction continued, in collaboration with Professor J. L. Jinks of the University of Birmingham (*Ann. Rep. 1977-78,* 24).

Cereal yields are strongly influenced both by the time and level of nitrogen fertilisation. Genetic variation for specific enzymes, such as nitrate reductase, may therefore be useful to plant breeders and would aid further genetic investigations. In 1978 a factorial experiment was grown to investigate varietal and environmental effects on nitrate reductase levels in the shoots and roots of barley. Two varieties, Golden Promise and Clipper, were grown at three nitrogen levels, 0, 35 and 70 kg ha^{-1} of nitrogen, and two hormonal treatments were applied, CCC (Cycocel) and gibberellic acid. Samples of leaves, stems and roots were collected throughout the growing season and will be assayed for nitrate reductase levels when development of a suitable automated method is complete.

Twenty triple test cross progenies from each of five pair-crosses, together with the respective parental, F_1, F_2 and backcross generations were raised in a field experiment in 1978. Each progeny was represented by a dibbed row of up to 20 plants, in each of four replications. The whole experiment was protected throughout the season with a cage of nylon net and was sprayed with a broad spectrum fungicide (Bayleton). Strong winds and heavy rain just before harvest caused the experiment to lodge. A CASE award student, Miss Sandra Thomas, measured a number of variates on single plants within each row and on whole rows. In the field, five plants in each row were scored for height at two growth stages, time to reach each of three developmental stages, and grain number on the main tiller. All of the rows were harvested as bundles of single plants and, because of harvesting damage, some single plant characters were rescored on intact plants. Grain number and grain weight on the main stem, number of fertile stems, height and neck length were scored on five intact plants from each row. The number of mature plants per row was also recorded together with threshed grain weight. The threshed bulks will be scored for thousand corn weight and small-scale chemical tests will be carried out.

The F_2 populations of the five pair-crosses were grown at the Murrays in 1977 as spaced plants and a number of plants was taken at random from each population. After two generations of single seed descent under glasshouse conditions, the progeny were multiplied in New Zealand during the winter of 1978-79; yield trials will be grown at the Murrays in 1979 to assess the genetic potential of each cross. Plants with short straw were selected from the same F_2 populations, with the exception of those from the cross Clipper × Ymer, which was an "exotic" cross which did not warrant such treatment.

These selections were grown for one generation using single seed descent during the winter of 1977-78. The resulting grains from each plant were sown as F_4 clumps at the Murrays in 1978 and further selection pressure was applied for early maturity and resistance to mildew and yellow rust. These selections will be re-assessed in 1979 and grown in trials in 1980 to estimate the realised gains from selection in the four crosses concerned. The triple test cross predictions, the genetic potentials and the realized potentials of the crosses can then be compared to assess the value of such test-cross programmes for prediction.

Analysis of crosses made to map several dwarfing genes present in commercial barley varieties continued in 1978. The F_2 populations of these crosses were grown as spaced plants at the Murrays and mature plants were recovered intact.

Investigations are being carried out into the linkage relationships between the dwarfing genes and other genes of known location on each of the seven barley chromosomes.

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Barley Biochemistry

Barley samples from a replicated trial of current varieties were milled in a new apparatus called a "Comparamill" which measures the energy required to mill the samples. Milling energy measurements on barley samples from individual plots correlated well ($r = -0{\cdot}76$) with hot water extracts of micro-malted samples. A total of 480 cultivars from the barley museum was analysed for milling energy on the "Comparamill" and for soluble β-glucan content on the InfraAlyzer. Of these, nine cultivars were lower in both characteristics than Gerkra, a barley with good malting quality. Work continued on the production of well adapted, high diastase barleys from crosses between parents with different forms of beta amylase.

A new milling apparatus, based on a flywheel system, for the measurement of energy required to mill a barley sample was developed, in collaboration with Calan Electronics Ltd. Potential applications of this new system, called a "Comparamill", were assessed. It was established that milling energy determinations by the "Comparamill" were more repeatable than on the original milling energy equipment (*Ann. Rep. 1976-77*, 60). A total of thirty samples from individual plots of a replicated trial with current cultivars were milled using the "Comparamill". Milling energy values correlated well ($r = -0{\cdot}76$)

Figure 14 p. 129) with hot water extracts of micromalted samples. However, three samples of the variety Mazurka did not fall on the general regression line. Despite low milling energy values, they gave poor extracts. Comparisons of enzyme activity showed that all three Mazurka samples with poor extract had very low α-amylase activity, whereas one Mazurka sample grown at a different site was high in α-amylase and this sample fitted the milling energy versus extract regression. Thus it seems that Mazurka usually has a "soft" endosperm capable of modifying rapidly, but extracts may be poor depending on hydrolase production during malting, and this, in turn, is subject to an environmental effect.

Two screening tests for aspects of malting quality, milling energy and the use of the InfraAlyzer to predict soluble beta-glucan, were applied to a representative sample of 480 cultivars from our barley museum collection. The results demonstrated variation for grain hardness and β-glucan content with eighteen cultivars having a lower milling energy, and more than 100 cultivars with a lower soluble β-glucan content than Gerkra, a barley with good malting quality. Of these, nine cultivars were lower for both characteristics.

Crosses involving the lines of very high β-amylase activity, derived from crosses between the varieties Akka and Feebar, (*Ann. Rep. 1977-78,* 25) were assessed, in the field, at F_2. Plants showing the semi-prostrate dwarfing habit and apparent resistance to mildew and yellow rust were selected, and seed from these will be sown as rows in 1979, when preliminary testing will be done to assess potential diastatic power. Studies in the prediction of diastatic power also continued, and a number of lines from the 1978 harvest are being assessed for electrophoretic pattern.

M. J. Allison
J. S. Swanston

Barley Breeding

The development of techniques to encourage disease epidemics, as an aid to breeding for resistance, continued. The first barley varieties were entered for NLT in 1979. All routine data handling in the breeding programmes has been computerised. Collaboration with PBI in the investigation of varietal mixtures for the control of mildew continued.

Localised epidemics of powdery mildew (*Erysiphe graminis*) and yellow rust (*Puccinia striiformis*) were generated at the Murrays from a strip of autumn-sown susceptible varieties surrounding the trials area. Worthwhile selection for resistance to both diseases was possible in all trials.

Nurseries were established for yellow rust, brown rust (*P.hordei*) and *Rhynchosporium*. The nurseries for the two rusts were established using a susceptible spreader variety with good mildew resistance. The spreader

variety was inoculated, by syringe, with spore suspension in hot, dry weather in May and, at the same time, infected seedlings were transplanted from the glasshouse. Disease development was slow but over 2800 entries in the barley collection and all breeding material from F_4 and later generations were scored for resistance to a complex race of *P. striiformis* (carrying V factors one to five). Unfortunately, a natural epidemic of yellow rust prevented effective assessment in the brown rust nursery. The assessment of *Rhynchosporium* resistance was also unsuccessful, possibly because no autumn sowing was possible in 1977 in the nursery and the spreader varieties were spring sown in 1978. Chopped barley straw from the well-infected nursery of the previous year (*Ann. Rep. 1977-78*, 26) was spread on the susceptible spreader varieties but despite daily irrigation the disease failed to develop. This may indicate that autumn sowing is essential for good disease development but it is possible that the viability of the inoculum was reduced as a result of the straw being baled and stored under damp conditions. Mildew resistance was assessed in the barley collection, this was possible because a natural epidemic developed on the multiplication nursery, assisted by the presence of spreader rows of the susceptible variety, Golden Promise.

For the first time, since the inception of the present barley breeding programme, two selections were submitted for inclusion in NLT to be grown in 1979. These were SPBS 69/13/3, a feed barley from the cross Hassan × Universe and SPBS MM 39/16, an EMS-induced mutation of Maris Mink with enhanced diastatic power originally selected by Dr M. J. Allison of the Chemistry Department. A number of selections from the crosses BR 83 (Maris Mink × Mazurka), BH 4 (Akka × Midas), BH 213 (Akka × Maris Mink), BH 644 and 648 (Akka × Maris Mink^2), BE 63 (Armelle × Maris Mink) and BE 353 (Armelle × Mimi) has been retained for final trials in 1979 and possible submission to NLT in 1980. Selections from four other crosses of Akka × Maris Mink^2 have been retained from F_6 trials for further evaluation in 1979. At F_5, one diastase selection from the cross (Akka × Midas) × Trumpf, three general purpose feed selections from Georgie × Trumpf and two selections with malting potential from Ark Royal × Trumpf have been retained. Approximately 450 selections were evaluated in F_4 trials and the most promising are being selected (during the UK winter months) in New Zealand. The remainder will be assessed in F_5 trials in 1979. Effective selection for mildew and yellow rust resistance was possible in both F_3 and F_2 nurseries and the most promising F_3 selections have also been advanced in New Zealand.

There is an urgent need for equipment to space-plant large F_2 populations; the existing NIAE dibber is already over-worked at sowing time and is not completely suitable. The use of the Scottish Plot Seeder for low density sowing was not successful. Development of the transverse seeder, in conjunction with SIAE, has continued in 1978 and will be used, for the first time, to sow a substantial part of the breeding material in 1979.

Generalised lattice designs (*Ann. Rep. 1977-78,* 26) are now used routinely in the breeding programme for yield trials of F_4 and subsequent generations. With total numbers of entries restricted to 100 or less and a minimum of one control variety in each block the general algorithm contained in the ARC Unit of Statistics "CVT" program has been used to generate designs. All routine data handling, including the designing of trials and the analysis and summarisation of data plus the generation of field note-books and plot labels, is now handled by this program using a series of procedures developed by Mr J. Brown.

The site at West Byres Farm, East Lothian which was used to investigate the effects of low soil pH on barley varieties (*Ann. Rep. 1977-78,* 24) was used in 1978 to screen segregating composite cross populations for acid-tolerance. The seed harvested from these plots will be sown at the Murrays in 1979 to complete the first cycle of recombination and selection. Recurrent selection for male-sterility and acid-tolerance will be continued for a number of generations.

The investigations, in collaboration with Dr M. S. Wolfe of the PBI, of the use of mixtures of varieties, for the control of mildew, were continued for a further year.

A trial was grown in which nine experimental treatments (five pure-stands and four mixtures) were compared for yield and mildew resistance. These treatments consisted of pure-stands, without fungicide application, of each of the cultivars, Hassan, Midas and Wing plus two other pure-stands, one of Hassan treated with the fungicide triforine and one of Wing plus ethirimol. The four mixtures all contained three cultivars, one with all components untreated, one each with either Hassan or Wing treated and one with both treated with fungicide. Mildew was late in arriving and levels of infection were low. There were no significant differences between treatment for plot yield at fifteen per cent moisture content nor for yield adjusted by regression on the yields of adjacent plots of Golden Promise.

A similar trial had been grown in 1977 at nine sites and analysis of the data from that trial indicated that mildew levels can be significantly reduced using mixtures. Mixtures generally appear to give a small yield advantage and there is considerable potential for further diversification, in which both varieties and fungicide treatments are varied. These experiments are being continued for a third year. Two additional trials were grown to investigate the effects of variety mixtures, in one trial the effects of mixtures and mildew on malting quality are also being studied.

Mobile seedling nurseries of selected barley genotypes were used to monitor the frequencies of *E.graminis* virulence genes in populations at a number of sites at the Murrays throughout the growing season.

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Oat Breeding

Of the four SPBS varieties which had reached the NLT/RLT stage, only Fyne is being retained. The line Aa 773, provisionally named Portmore, completed NLT1. The first F2 material from the pedigree breeding programme was grown in the field. The set of crosses required for a small genetic experiment has been completed. Studies on oat physiology continued.

The varieties Leven (Aa 749) and Etive (Aa 752) completed second year RLT for the Scottish Colleges, but were not recommended. Earn (Aa 758) was withdrawn on completion of NLT2, being indistinguishable from Fyne (Aa 760). Fyne also completed NLT2 and received a grant of plant breeders rights; multiplication stocks were passed from the Cereals Department to NSDO for further multiplication. Fyne was also grown in first year RLT by Scottish Colleges in 1978 and performed sufficiently well to be retained for a second year. In England and Wales, Fyne has been accepted for first year RLT by NIAB. Aa 773 has been provisionally named Portmore and successfully completed NLT1 in 1978. This material is the last to come from the oat breeding programme developed by Mr D. Cameron and based on composite cross methods. The populations have been retained but the emphasis in breeding has been moved to pedigree methods.

The first material in the pedigree programme was sown as spaced plants at F_2 in 1978. Oat crossing proved to be more difficult than for barley and only small hybrid populations were obtained. Effective selection was difficult due to severe attack by frit-fly (*Oscinella frit*) but a number of F_3 progenies has been retained for evaluation as ear-rows. Four pair-crosses were selected for investigation of a number of quantitative characters and appropriate crosses for a small genetic investigation (parents, F_1, F_2, backcrosses) were prepared in 1978. Oat physiological studies were confined to the measurement of dry weight changes during the development of Maris Tabard, Omihi, Trafalgar and Fyne. The data demonstrated that oats reached maximum dry weight later in the growing season than did barley. This slower development and the more complex pattern of apical primordium development during panicle production may explain the commonly observed lower productivity of oats in comparisons with barley in terms of dry weight of grain produced.

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Cereal Collections

Work continued on the collection of spring barley data and its incorporation into the EXIR data bank. Difficulties were experienced in comparisons of descriptors from different institutes. Multiplication of the Hordeum spontaneum *collection continued but on a smaller scale than last year.*

The barley and oat collections were both grown at the Murrays but field observations were not made on the oat collection, which was heavily attacked by frit-fly (*Oscinella frit*). A further attempt to increase the stocks of the oat collection will be made in 1979 as seed reserves are depleted. New accessions bring the SPBS barley and oat collections to 2914 and 1130 entries, respectively.

EXIR

Work continued on the collecting and filing of information for the barley collection. Experience in the use of EXIR demonstrated its potential value to cereal breeders but also revealed a serious short-coming in the incompleteness of the data matrices of the barley data bank. Considerable effort is now required to make up these deficiencies while also keeping pace with the influx of new accessions. Greater effort to screen the collections and to incorporate existing bodies of data would further increase the value of the bank. Difficulty has been experienced in comparing descriptor states of varieties common to more than one of the participating stations (SPBS, WPBS and PBI). This stems both from different interpretations of descriptors and from seasonal variation in characteristics such as disease susceptibility. Further agreement between the stations is required so that information in the bank may become more uniform.

Turn-round time of EXIR jobs has been improved by the introduction of the NUMAC link between the University of Newcastle and the University of Cambridge Computing Laboratory. Output for jobs initiated at the Remote Job Entry Terminal at Pentlandfield, and run in Cambridge, can now be printed at the Edinburgh Regional Computing Centre via NUMAC. Turn-round time is now comparable with that of jobs run locally at ERCC and mailing of output from Cambridge has been eliminated.

HORDEUM SPONTANEUM

The first phase of the programme to multiply *Hordeum spontaneum* material from Israel has been completed and the second phase has commenced. Pressures on resources at the three participating institutes (SPBS, WPBS and PBI) have prompted the decision to extend the duration of the programme from five to eight years to allow smaller sowings in any one year. Approximately 2000 seeds will be sown annually at each station rather than the 3500 to 4000 attempted in the first phase.

R. J. Giles

Studies of Swede Hybrids

The isolation of S-alleles and their introgression into swedes continued. An 11 × 11 half-diallel trial was examined to identify high-yielding F_1 hybrids.

SELF-INCOMPATIBILITY

Out of sixteen self-incompatible lines tested, only three appeared homozygous for their S-alleles. Plants of all the lines were selfed for multiplication or further testing and back-crosses were also made to normal, self-compatible swedes to produce lines which were heterozygous for self-compatibility and self-incompatibility. These plants are to be isolated with white-fleshed swedes to examine the ability of their S-alleles to enforce outcrossing. Sister plants will be scored for pollen tube growth to compare laboratory results with those found in the field.

Another 40 possible homozygous S-allele lines have been produced, involving four more swede cultivars and four different S-alleles. The introduction of further cultivars into the back-crossing programme continued and nine different S-alleles have now been isolated. Thirty-three backcross lines were examined and seed produced from twenty of these for future use. Six of the most advanced lines have been sown for testing for incompatibility this year.

F_1 HYBRID TRIAL

Sufficient seed was produced by hand pollination to extend a half-diallel to 11 × 11, with the exception of four of the 55 crosses involved. The seed was sown in trial using a single drill Stanhay precision seeder. Thirty-seven of the F_1 hybrids had fresh weight yields which were higher than those of their higher parent, nineteen were significantly so ($P<0{\cdot}05$) and, of these, two were significantly higher than the highest yielding parent ($P<0{\cdot}05$). For dry matter yield, 36 hybrids exceeded the yield of their higher parent, with increases of up to 25 per cent being found. The highest yielding hybrid was thirteen per cent higher than the highest parent, but this was not significant ($P<0{\cdot}05$). The dry matter contents of the hybrids were, in the main, intermediate between those of their parents. The exceptions were one which was higher and four which were lower than both parents, and none of these differed significantly from the nearer parental value. An analysis of combining abilities showed highly significant levels of general combining ability (GCA) for fresh weight and dry weight yield ($P<0{\cdot}001$) but no specific combining ability (SCA). For dry matter content, it was found that SCA was also highly significant, with an amount equal to half that for GCA (Table 1).

TABLE 1

Analysis of combining abilities from a diallel cross of swedes.

		df	*Mean squares*	*F*
Fresh weight yield	GCA	10	1482·27	13·68***
	SCA	40	94·54	0·87NS
	Error	195	108·34	
Dry matter content	GCA	10	6·958	14·33***
	SCA	40	0·485	5·02***
	Error	195	0·097	
Dry weight yield	GCA	10	5·523	4·93***
	SCA	40	0·732	0·65NS
	Error	195	1·121	

***$P<0.001$

S. Gowers

Swede Breeding

Programmes for the production of high-yielding lines, from inter-cultivar crosses and by inbreeding within cultivars; and for the introgression of turnip characters into swedes were continued. Two advanced swede lines have been entered for National List Trials. A small mutation breeding programme was commenced. A survey was made of the incidence of turnip crinkle virus on swedes at several trial sites. In addition to the work on swedes, a small trial of fodder beet was conducted.

INBRED LINES FROM INTER-CULTIVAR AND OTHER CROSSES

Improvement in disease resistance and yield components (in particular dry matter content) are among the most important aims of the swede inbreeding programme. Also important are improvements in frost tolerance, keeping quality and suitability for mechanical harvesting or *in situ* grazing.

As part of the programme to improve disease resistance, crosses were made in 1978 between swede cultivars and lines of swede, rape and artificial *Brassica napus* which had resistance to either club root (*Plasmodiophora brassicae*) or powdery mildew (*Erysiphe cruciferarum*). Plants of the F1 generation of these crosses are being grown on to produce F2 seed in 1980. Single plants will be selected from this generation for the characters listed above.

The programme to produce swedes with high growth rates and high yields of foliage (*Ann. Rep. 1977-78*, 30) was continued. Fifty plants from crosses between Canard rape and six swede cultivars were selected for leafiness and root size and were self-pollinated in 1978. The F2 generation of this material will be grown for selection in 1979, with emphasis on fresh weight yield and resistance to powdery mildew.

Plants were selected from an existing F_2 population derived from crosses between eleven cultivars or lines, including Doon Major and APZ (*Ann. Rep. 1971-72,* 24 and *1977-78,* 31). The selections were made (visually) for root size, winter hardiness and resistance to powdery mildew and virus infections. From 2000 F_2 plants, 248 were retained for self-pollination to produce F_3 seed in 1978. Particular emphasis will be placed on selection for both low and high dry matter content.

The F_2 populations derived from twelve crosses between sixteen cultivars or lines of swede, including Marian and Criffel, two of the highest yielding cultivars, were grown together with the control cultivars Marian, Merrick, Ruta Otofte and Pentland Harvester. Approximately 16,000 plants were available from which to select.

Plants were assessed visually for root size, disease resistance, (including freedom from rotting) and winter hardiness, and 300 were selected for self-pollination to produce seed for an F_3 generation in 1980.

Data from the F_3 trial, grown at the Murrays in 1977, indicated that none of the "selections" outyielded Ruta Otofte (*Ann. Rep. 1977-78,* 31). However, to permit assessment of other characters and to maintain continuity of generations in the breeding programme, some plants were transplanted for self-pollination and seed production. Three separate lines were chosen from the cross Ruta Otofte × Gullacker and one line each from the crosses Ruta Otofte × Bangholm Sahna, Ruta Otofte × Wilhelmsburger Danila and Ruta Otofte × Pentland Harvester. Selections will be made from the F_4 plants with particular emphasis being placed on disease resistance, dry matter content, resistance to internal browning (or "raan") and winter hardiness.

One hundred and ninety-six F_3 lines (derived from crosses made in 1966 and 1967 between eight of the highest yielding cultivars then available), were grown in a partially replicated trial together with six control varieties. The trial was scored visually for disease resistance, bulb and foliage characters, neck length and winter hardiness. Plants of the twenty lines with the highest dry matter yields (ranging from 100 to 143 per cent of the mean of the controls) were retained for the production of F_4 seed in 1979.

It was not possible to include detailed analysis of the F_5 and F_6 trials mentioned in last year's report (*Ann. Rep. 1977-78,* 29-30). However, from the analysis of the F_6 trial data, it was found that 25 lines were higher in dry matter yield than the overall mean of the controls and of these, thirteen were significantly higher ($P<0{\cdot}05$).

Sufficient seed was still available of 21 of these F_6 lines to grow them in trial again in 1978, together with nine lines from the 1977 F_5 trial. The 21 F_6 lines were derived from crosses between Bangholm Wilby and several strains of Wilhelmsburger, while the nine F_5 lines were from a cross between Teviotdale and an SPBS selection from Champion. This trial was laid out in four randomised blocks and included five controls along with the two advanced lines Da9939 (now SPBS 9939) and Da9943 (now SPBS 9943) both of which

have been sent for National List Trials. Analysis of the dry matter yield data showed that six lines were significantly higher, for this character, than the main control Ruta Otofte ($P<0.05$); four of these are F_6 and two are F_5 inbreds. These six lines also out-yielded the highest yielding control Marian, though the difference was not significant. SPBS 9939 and SPBS 9943 were both lower in dry matter yield than Ruta Otofte though not significantly so but both were higher in dry matter content than any of the controls.

A second trial, of similar design to the above, included eighteen F_5 lines (produced in 1977 from F_4 material which had done well in trial in 1976) together with eight F_6 lines and five controls. The F_5 lines were derived from crosses between Pentland Harvester and the selection from Champion (see above), while the F_6 lines were from hybrids between various Bangholm cultivars and Pentland Harvester. In this trial only one of the F_5 lines exceeded Ruta Otofte in dry matter yield, but not significantly so, though 22 lines were significantly higher than Marian, as were three of the other controls ($P<0.05$).

A third trial, again laid out as four randomised blocks, consisted of twelve multiplications of F_5 lines which had performed well in trial in 1976, these lines were derived from crosses having Pentland Harvester as one parent. Three controls were included. Two of the multiplications out-yielded Ruta Otofte in dry matter yield, but neither was significantly higher ($P<0.05$).

The Field Trials Unit carried out trials at three sites, Threshy Park, near Pentlandfield; Cockle Park, University of Newcastle Experimental Farm, Northumberland and Tullochgorum, Inverness-shire to provide further data on SPBS 9939 and SPBS 9943. Harvesting has not been attempted (22.2.79) at Tullochgorum because of continued frosty conditions. The results for the other two sites are given in Table 2. The dry matter content of both lines at

TABLE 2

Performance of SPBS 9939 and SPBS 9943 and of six cultivars at two sites in 1978. Fresh and Dry Weights are given as percentages of Ruta Otofte.

	Threshy Park			*Cockle Park*		
	Fresh weight yield	*Dry matter %*	*Dry weight yield*	*Fresh weight yield*	*Dry matter %*	*Dry weight yield*
Ruta Otofte	100	9·5	100	100	13·1	100
SPBS 9939	85	10·5	94	107	14·8	124
SPBS 9943	83	10·7	93	97	14·7	112
Bangholm Magres	89	9·5	89	112	11·9	104
Wilhelmsburger Sator	83	9·5	84	103	14·1	113
Marian	101	8·8	94	144	10·8	121
Criffel	98	8·9	93	161	10·1	127
Doon Major	101	8·4	89	151	9·5	112
Least significant difference ($P<0.05$)	15·6	0·58	1·9	20·6	1·8	1·7

both sites was higher than that of any of the controls. At Threshy Park, on light soil, both lines had dry matter yields significantly lower ($P<0.05$) than that of Ruta Otofte although as good or better than those of the other controls. At Cockle Park both lines significantly out-yielded Ruta Otofte.

A further trial at Carnoustie, Angus, also included SPBS 9939 and SPBS 9943. The results are given in Table 3 for these two lines and the controls only.

TABLE 3

Performance of SPBS 9939 and SPBS 9943 and four cultivars at Carnoustie in 1978. Fresh weight and dry weight yields are given as percentages of Ruta Otofte.

	Fresh weight yield	*Dry matter %*	*Dry matter yield*
Ruta Otofte	100	10·0	100
SPBS 9939	92	11·7	107
SPBS 9943	93	11·9	111
Wilhelmsburger Sator	95	10·4	99
Marian	109	9·2	100
Criffel	102	9·2	94
Least significant difference ($P<0.05$)	14·3	0·74	1·7

"Raan", caused by boron deficiency, has not been a problem in these two lines, but both are susceptible to mildew.

W. H. Macfarlane Smith
Isabel K. Munro

MUTATION BREEDING

A breeding programme of the type described in the previous section may well lead to improved disease resistance, particularly where one of the parents used in the crossing programme is an artificially produced *B.napus* line, having club root or mildew resistance obtained from *B.campestris* or *B.oleracea*. Other means of improving disease resistance have been considered and a small mutation breeding programme, aimed at obtaining improved disease resistance in both swede and rape, has been started. The chemical mutagen, ethyl methane sulphonate (EMS), is being used and experiments so far have been confined to the determination of the optimum concentration of EMS for mutation induction and investigations into the most suitable techniques for screening disease resistance in the EMS treated material

W. H. Macfarlane Smith

A number of lines from crosses between stubble-turnips and swedes was available for trials in 1978 (*Ann. Rep. 1977-78,* 32). Although 36 lines had been selected only 26 produced sufficient seed for both trial and the necessary observation plots. A replicated experiment was sown with the swede cultivars Marian, Merrick and Pentland Harvester as controls. The area used for this trial suffered severely from water logging and the results must be treated with some caution. None of the hybrids equalled the fresh weight yield of the best control though in several cases the dry matter content was higher. Plants of the best ten hybrid lines were retained for seed production and further testing, including screening for chromosome number.

TABLE 4

Performance of *B.napus* × *B.campestris* hybrids in comparison with swede varieties, in Threshy Park, Pentlandfield, in 1978.

Line	*Fresh weight yield kg/plot*	*Dry matter %*	*Dry weight yield kg/plot*	*Dry weight as a percentage of controls*	*Colour G – green B – bronze P – purple*
3MC3b	67·5	9·2	6·21	114	P
3MD4d	61·5	9·3	5·72	105	B
3MD4a	60·5	8·5	5·14	94	G
3NS1a	58·0	10·4	6·03	110	B
3ND2b	56·0	10·0	5·60	102	B
3MC3c	54·0	8·5	4·59	84	G
3VC1b	53·5	10·0	5·35	98	P
3MC1a	53·3	9·7	5·17	95	B
3ND3c	50·5	10·0	5·05	92	G
3MC1b	49·5	10·0	4·95	90	B
Merrick	68·3	8·6	5·87	107	B
Marian	64·6	9·1	5·88	107	P
Pentland Harvester	49·7	9·4	4·67	85	P

W. H. Macfarlane Smith

INBREEDING WITHIN CULTIVARS

With the object of producing a more diverse set of inbreds for the F1 hybrid programme, lines from nine cultivars of widely differing origin were sown for trial and selection. These lines included several with low dry matter content, as the previous range was mainly of medium and high dry matter cultivars. Selections from this latter group were bag-selfed to produce seed for trial in 1979.

In the 1977 trial of inbreds from the cultivar, Scotia, the top two groups, each consisting of ten families derived from a common grandparent, gave mean yields eight per cent and five per cent higher than Scotia, but these differences were not significant ($P<0{\cdot}05$). The top four families from each group were again grown in trial in 1978 with an increased number of

replications. The means of the groups were twelve per cent ($P<0{\cdot}01$) and eight per cent ($P<0{\cdot}05$) higher than Scotia. These results indicate that inbreeding and selection within a cultivar is capable of producing higher yielding as well as more uniform lines and confirms earlier work on swede breeding (*Ann. Rep. 1938,* 29). Multiplications between and within the groups have been made and a further set of selfs has been produced. Trials of this material should show the level of inbreeding to which such lines should be subjected.

Second generation inbreds from Bangholm Dima were sown in trial, with both high and low selection lines included to give estimates of the response to selection. From 50 lines examined in 1976 nineteen were selected, being the top five and bottom five for fresh weight, dry matter content and dry matter yield. There was a significant regression ($P<0{\cdot}01$) of dry weight yield on plant population, and selections were also made on adjusted dry weight yields. Estimates of heritabilities made from these results gave values of 0·25 for both fresh weight and for dry matter yield and 0·40 for dry matter content. With the selections made on the basis of adjusted dry weight yield there was no significant difference between the means of the high and low selection lines ($P<0{\cdot}05$). In the 1978 trial the high selections in this group did not include the two highest yielding families, one of which was selected on unadjusted dry weight yield and the other on dry matter content. The regression of progeny group means on parental family means was also used to give rough estimates of heritabilities. For dry weight yield the same result of 0·25 was obtained, but fresh weight and dry matter percentage gave slightly higher estimates with 0·37 and 0·47 respectively. The means of the first and second generation inbred lines were 6·8 per cent and 7·5 per cent lower than the control, Bangholm Dima. These figures were used to estimate the dominance component of dry matter yield. Assuming Dima to be self-compatible, an estimate of 83 per cent selfing (*Ann. Rep. 1976-77,* 29) was used to estimate an inbreeding coefficient of 0·7 for the parent cultivar. Using these values, a backward projection was made to estimate the probable yield of a theoretical outbreeding base population which predicted that the dry weight yield of such a population would be 28 per cent higher than Dima. Introducing S-alleles to convert swede cultivars into outbreeders could, therefore, be a possible alternative to F_1 hybrid production.

Further selections have been made from this material in an effort to obtain higher yielding and uniform lines. Unfortunately, the family with the best scores for mildew and internal browning had a mean dry weight yield below that of the general mean. With an overall inbreeding coefficient of over 0·9, it is unlikely that much progress will be made in producing a higher yielding line from this family.

Results from the trial of second generation inbred lines from the cultivar Criffel, showed two promising families, one with a dry weight yield five per cent higher than the mean of the Criffel and Ruta Otofte controls ($P<0{\cdot}05$),

the other being eleven per cent higher ($P<0{\cdot}05$). These lines will be of value in the F1 hybrid programme, as the results from the F1 hybrid trial showed Criffel to have the highest general combining ability. A yellow fleshed line from this material would be useful, but such lines isolated so far appear to be lower yielding than the white fleshed or segregating lines selected.

S. Gowers

SELECTION FOR HIGH DRY MATTER CONTENT

An experiment was carried out to compare oven temperatures of 60°C, 80°C and 100°C with freeze drying for their effects on dry matter determinations of core samples of swedes. Results at 60°C did not differ significantly from freeze drying ($P<0{\cdot}05$); at 80°C, some of the results obtained differed significantly and at 100°C all results were significantly different, in the range 1·0 to 1·7 per cent in dry matter content. The interaction between cultivars and drying temperatures was also significant.

Drying temperatures of 80°C have previously been used in selecting for high dry matter content. Because of the significant interaction in the core drying experiment further selections have been made using freeze drying for determinations of dry matter content. One hundred roots of a Bangholm Wilby line, coded BWc, (*Ann. Rep. 1977-78,* 32) were tested and eighteen were selected on their deviations from the regression of dry matter content on fresh weight yield. The dry matter content in the selected plants ranged from 15·0 to 17·5 per cent.

Of the 50 selections made previously, using oven drying to determine dry matter contents, only 25 produced sufficient seed to sow in trial. Seventeen of these were plants from BWc. One thousand plants are to be tested and selections made on the basis of the deviations from the regression of dry matter content on fresh weight yield.

S. Gowers

TURNIP CRINKLE VIRUS SURVEY IN SWEDES

Severe symptoms of turnip crinkle virus, which is transmitted by flea beetle (*Phyllotreta* spp.), have been reported by Dixon *et al* (*Pl. Path.* 24, 31-32) to occur on swede cultivars in some years, but symptomless infections may also occur (Broadbent. Investigation of virus diseases of Brassica Crops. *ARC Report No. 14, 1957*). The natural level of infection in swede crops in Scotland and northern England was investigated by sampling from six cultivars at five sites. Leaf samples were collected from the cultivars Criffel, Doon Major, Marian, Ruta Otofte, Vogesa and Wilhelmsburger Sator Otofte which have shown a range in severity of symptoms in NLT at Headley Hall (North Humberside) in previous seasons. These cultivars were sampled from National List Swede Trials at two NIAB Regional Testing

Centres, Cockle Park (Northumberland) and Headley Hall, and from the trial sites of the three Scottish Colleges of Agriculture. No obvious symptoms were observed at any of these sites in 1978.

Mr W. P. Mowat at SHRI examined the leaf samples using enzyme linked immunosorbent assay (ELISA) with companion infectivity tests. Turnip crinkle virus was not detected in any samples by ELISA, but tomato black ring virus was detected by the infectivity tests in leaf samples from Craibstone, Aberdeen.

Cynthia J. Williamson

FODDER BEET TRIAL

At the request of the Brassica Research Committee of the SSRPB, an examination of modern cultivars of fodder beet and mangels has been made to compare them with swedes under Scottish conditions. Two small trials were grown, one near Pentlandfield and the other near Carnoustie, Angus, by courtesy of Mr W. H. Porter. Thirteen cultivars of fodder beet or mangel were sown, together with four cultivars of swede. Although there are two main groups of fodder beet and mangels, one with dry matter content between eighteen and twenty per cent and the other between eleven and thirteen per cent, there are a few intermediate varieties providing a continuous range from eleven to twenty per cent. The yields of fodder beet roots compared favourably with those of swedes.

TABLE 5

Performance of fodder beet and mangels in comparison with four high yielding swede cultivars.
(The names of the swede cultivars are underlined)

	Dry matter %	*Dry matter yield, t ha* $^{-1}$	
	Roots†	*Tops*‡	*Roots*†
Kyros (DPB)	18·5	4·2	12·6
Korsroc (DPB)	17·4	3·8	12·1
Vital (Dochnf.)	19·1	5·0	12·0
Majoral (Z & W)	16·2	3·9	12·0
Criffel (SMcG)	9·1	1·8	12·0
Monobomba (SMcG)	17·9	4·2	11·9
Monovert (Z & W)	19·1	4·3	11·8
Peramono (Sharpe)	14·1	3·3	11·8
Meka (DPB)	20·4	3·5	11·6
Monoval (Z & W)	16·8	4·2	11·6
Marian (NSDO)	8·9	1·9	11·4
Wintergold (Sharpe)	11·9	1·8	11·3
White Knight (SMcG)	13·2	3·1	11·0
Ruta Otofte (DPB)	9·9	1·7	10·6
Prizewinner (Sharpe)	11·5	2·6	10·6
Monorosa (SMcG)	20·8	4·7	10·0
Sator Otofte (DPB)	10·0	1·8	9·7
Least significant difference ($P<0·05$)	0·88	1·06	1·27

†=mean of Pentlandfield and Carnoustie
‡=Pentlandfield only

These results were obtained under conditions which would be expected to be more favourable to swedes; the trials were not sown until the beginning of May, and the summer was cold and wet. If the tops can be utilised, then fodder beet provides an extra four or five tonnes per hectare of dry weight, two or three times more than that available from swede tops. These results suggest that a revival of interest in the agronomy and breeding of fodder beet would be justified.

S. Gowers

SWEDE GENE BANK

Germination tests were made on the 93 oldest accessions of seed from DAFS Scientific Services, Edinburgh. Plants were eventually obtained from 62 seed stocks and were planted in insect cages for seeding. The remainder were grown under selfing bags, with several plants in each bag.

Isabel K. Munro

Turnip Breeding

A small programme has been started to improve the traditional type of turnip. Breeding objectives are high yield and good clubroot resistance.

A preliminary trial to examine a range of present day cultivars was carried out by the Field Trials Unit in 1977 at Tullochgorum, Inverness-shire (Table 6). Eighteen turnip and two swede cultivars were included, covering the

TABLE 6

Field Trials Unit Turnip Trials results, Tullochgorum, Inverness-shire 1977.

Variety	*Fresh weight t ha $^{-1}$*	*Dry matter %*	*Dry weight t ha $^{-1}$*	*Dry weight % of control*	*Colour**
Wallace (BRH)	65·8	9·2	6·05	100·0	G
Wallace (SMcG)	60·5	9·3	5·63	93·1	G
Findlay (NSCA)	57·3	9·8	5·60	92·6	G
Bruce (BRH)	73·0	9·2	6·70	110·7	P
Bruce (SMcG)	63·5	9·4	5·95	98·3	P
Brimmond (NSCA)	54·0	10·1	5·45	90·1	P
Yellow Tankard (BRH)	78·8	8·1	6·43	106·3	G
Yellow Tankard (DPB)	73·8	8·5	6·28	103·8	G
Green Top Yellow (Tucker)	83·3	8·3	6·88	113·7	G
Green Top Scotch (SMcG)	84·3	8·5	7·13	117·9	G
Aberdeen Green Top (BRH)	63·3	9·0	5·65	93·4	G
Aberdeen Purple Top (BRH)	59·5	9·3	5·58	92·2	P
Invincible (BRH)	79·0	8·3	6·58	108·8	G
Imperial (Johnstone)	89·0	7·9	7·08	117·0	G
Balmoral (BRH)	60·0	9·3	5·58	92·2	G
Folt (Norges Land.)	75·5	9·5	7·15	118·2	G
Hvit Mainepe (Norges Land.)	52·8	12·7	6·70	110·7	G
Sirius (Svalof). Tetraploid	90·3	7·9	7·13	117·9	G
Bangholm Ruta (DPB)	51·5	11·0	5·68	93·9	P
Wilhelmsburger Sator (DPB)	40·0	12·0	4·83	79·8	G
SE difference	2·43	0·27	0·26		

* G = green
P = purple

normal range of dry matter content from eight to ten per cent and also including the high dry matter Norwegian cultivar Hvit Mainepe which may have a dry matter content of over 12·5 per cent. From the results of this trial, two polycross populations were set up, both having green skin colour. The three white fleshed diploid cultivars Foll, Hvit Mainepe and Imperial were included in one polycross, and the other set contained Invincible, Green Top Scotch, Green Top Yellow and Wallace. Unfortunately many plants of the low dry matter content cultivar Imperial rotted and thus will have contributed little to the genetic composition of the polycross progeny.

Most traditional varieties of turnip appear to have little clubroot resistance, with the exception of some recent selections by the North of Scotland College of Agriculture. Stubble turnips, however, are a good source of resistance, especially those used in the European Clubroot Differential set. ECD 04 has been crossed to five of the top cultivars at the start of a backcrossing programme to introduce a high level of clubroot resistance.

Seven S-allele stocks of turnip (*Ann. Rep. 1976-77*, 32) were isolated in pairs, in insect cages, in a diallel arrangement and produced seed of all the possible F_1 hybrid combinations. The parents of these S-allele lines were of culinary or stubble-turnip origin and the F_1 hybrids were therefore sown in trial as catch crops. The parental S-allele lines were seriously affected by inbreeding depression, and even if sufficient seed had been available they would have been unsuitable for controls. The controls used were three stubble turnips, two agricultural turnips and two culinary turnips. Root and leaf yields were taken, and two of the hybrids gave significantly higher root yields than the controls ($P<0{\cdot}01$). One of these hybrids also had a high yield of tops, and its total yield was seventeen per cent higher than the highest control. Because of the difficulty of maintaining and multiplying the inbred lines the production of single cross hybrids is impracticable. Estimates of the yields of possible double-cross combinations were made from the means of the non-parental crosses. The highest estimates were only equal to the yield of the top control, and it was concluded that the production of a double-cross hybrid from this material is not worthwhile.

S. Gowers

Kale and Fodder Cabbage Breeding

Work continued on improving an outbreeding population of kale, and on deriving from it potential new varieties of kale. Selection for low levels of toxic factors is an important new breeding objective. Other kale material was assessed for possible inclusion in new outbreeding populations which will be set up with the expansion of the programme. A start has been made on a small fodder cabbage breeding programme. An investigation to compare various methods of popu-

lation improvement and variety production, using computer simulation techniques, was begun.

Nineteen seventy-eight saw changes in emphasis, an expansion of the existing kale improvement programme and the start of a small fodder cabbage breeding programme. More attention is now being given to the purpose for which fodder kale and cabbage are grown, namely for feeding to ruminant livestock during the autumn and winter months. The stock farmers concern is milk production and liveweight gain.

Priority is being given to ways of breeding for low levels of two toxic factors, S-methyl cysteine sulphoxide (SMCO) which is haemolytic and thiocyanate ion production which is goitrogenic. Also dry matter percentage and digestibility (DOMD%) are now viewed as important characters in their own right, rather than merely components of yield of digestible organic dry matter.

The acceptability to livestock (voluntary intake, palatability, edibility) and the amount of wastage when grazed *in situ* are more difficult to assess. SPBS are unable to carry out animal grazing experiments, and in any case, early in a breeding programme there are many lines to test, and only small quantities of seed available. Simple screening tests are required which correlate well with those characters.

This change in emphasis does not mean that other characteristics of the crop are being neglected. Fresh weight and digestible organic dry matter yield per hectare, winter hardiness, disease resistance, height and lodging resistance, and seed production are also taken into account.

The progress that has been made with an outbreeding population of "kale" was summarised in last year's annual report. (*Ann. Rep. 1977-78,* 33-34). In 1978 the S_3 generation of single-plant polycross progenies was grown both in a replicated yield trial and in observation plots. The trial grew well during the cold wet summer and autumn, and was harvested during November. The next generation will be selected from the observation plots once the toxic factor and digestibility analyses have been completed by the Chemistry Department.

During 1977 residual seed of the S_0, S_1 and S_2 generations was used to compare these populations in the same environment and hence to obtain a direct estimate of the response to selection. Unfortunately the trial, which was carried out at the Murrays, had a high coefficient of variation, but surprisingly, the results suggest that the three generations had similar yields of digestible organic dry matter which were, however, higher than the mean of the controls, Maris Kestrel and Canson. These higher yields were achieved primarily through a higher dry matter content.

While there is now some doubt over the reality of the response to selection for yield of digestible organic dry matter, there is no doubt that selection for this trait has had an effect on plant morphology. The S_0 generation (*Ann. Rep. 1973-74,* 14-15) included marrow-stem kales, thousand headed kales, curly

kales, brussels sprouts, cabbages, and intervarietal hybrids. The S_3 generation consists entirely of marrow-stem types, and indeed, in the yield trial it was difficult to see the boundary between plots.

The data from the trial of five "pre-varietal stocks" from the S_1 generation (*Ann. Rep. 1977-78,* 34) which was carried out by the Trials Unit, at three sites in 1977, was analysed. The yields of digestible organic dry matter of the stocks fell between those of Canson and Giganta (the higher) and were similar to Maris Kestrel. These yields are not considered high enough, nor are the stocks considered uniform enough, for NLT submission. However, off-types were discarded from the best stock in 1978 and a bulk of seed was obtained in the autumn for further assessment.

Of the four single plant progenies from the S_2 generation, mass multiplied in 1977, sufficient seed was obtained from two of them to be included in Trials Unit trials at Ayr, Cockle Park, and Threshy Park (near Pentlandfield) in 1978. The other two families were included in the main S_3 generation trial. Further seed multiplication of S_2 families were carried out during 1978. The future of this programme will depend on the performances of the S_3 and S_4 generations, together with the results of a biometrical genetical analysis of the populations, during the next two to three years.

In last year's annual report (*Ann. Rep. 1977-78,* 33-34) it was recorded that no work was carried out in 1977 on the reciprocal recurrent selection programme. Seed from selections was sown and agronomic assessments made during 1978. The history of the material is complicated, it derived from a biometrical genetical investigation of variation in *Brassica oleracea* involving cultivars of marrow-stem kale, thousand-head kale, curly kale, and cabbages carried out in 1971 and 1972 (*Ann. Rep. 1973-74,* 14-15). It had not been subjected to intense selection, but had been inbred. The result is that the material is still morphologically very variable, and lacks vigour. It has been decided to discontinue the reciprocal recurrent selection programme as such, and to include the best of this material in a new population.

A start has been made in comparing methods of population improvement and variety production through computer simulation techniques.

J. E. Bradshaw

Rape Breeding

A number of crosses were made between existing cultivars and artificial Brassica napus *to provide material on which to base a conventional breeding programme to produce disease resistant and productive varieties. Promising F_3 lines were obtained from another breeding programme.*

A major objective of the programme is the production of disease resistant, commercially acceptable rape cultivars. The most promising method of

achieving this is by selection amongst the progeny of crosses between existing rape cultivars and artificially synthesised *Brassica napus* having resistance to *Erysiphe cruciferarum* (mildew) and to *Plasmodiophora brassicae* (club-root). In 1978 many crosses were made of this type using forms of artificial *B.napus* with a leaf to stem ratio higher than that of existing cultivars. A number of crosses were also made between existing cultivars in order to provide material for an expanded selection programme and seed for use in mutation experiments.

A few plants of some hybrid rape lines, grown at the Murrays in 1977, were still alive in April 1978. A number of these plants were transplanted for self-pollination and the production of seed for F3 trials in 1979. Among the parent plants used in the production of this material were semi-artificial rapes and a rape low in thiocyanate content (obtained from the Swedish Seed Association at Svalöf).

W. H. Macfarlane Smith
C. L. Ross

Exploitation of Inter-specific Crosses as Possible Rape Substitutes or as New Forage Species

Some of the most advanced semi-artificial rape lines show promise in being high yielding with a good degree of tolerance to powdery mildew. These lines are morphologically distinct from current commercial cultivars.

DEVELOPMENT OF SEMI-ARTIFICIAL RAPES

Twenty-four F5 semi-artificial rape lines (individual plant progenies) were compared with six leading commercial rape cultivars (Bishop, Canard, Emerald, Lair, Nevin and Samo) in trials carried out in 1978 in Threshy Park (near Pentlandfield). Samo is a Swedish cultivar bred at Svalöf and is low in thiocyanate content. The parentage of the semi-artificial rape lines is of two basic origins (*Ann. Rep. 1977-78,* 85-6).

Three lines out-yielded all six controls, two others giving dry matter yields equal to the best control. These five lines, coded AR5, have the oriental *Brassica campestris* ssp. *nipposinica* in their parentage. Lines with *B.campestris* ssp. *pekinensis* (Chinese cabbage) in their parentage, coded AR6, performed less well and were generally susceptible to powdery mildew which was prevalent, probably due to the relatively early (mid-June) sowing of the trial. Some premature flowering occurred in some of the lines. The AR5 lines were relatively unaffected by mildew, a number of them giving scores equal to the best control. The trial was sampled for analyses of SMCO and thiocyanate content by the Chemistry Department.

The AR5 and AR6 lines are leafy and appear morphologically distinct from each other and from the commercial cultivars with which they have been compared.

Two AR5 and AR6 semi-artificial rape bulks (mixtures of a number of individual plant progenies) were compared with rape cultivars, Emerald and Lair, at two sites, Threshy Park, near Pentlandfield and Yonderton (Ayr). These trials were conducted by the Trials Unit, results are shown in Table 7. Dry matter yield of the AR5 bulk was significantly lower ($P<0.05$) than the best cultivars, Emerald, at Threshy Park, a contributory factor being its lower dry matter content. At Yonderton differences in dry matter yield between semi-artificials and cultivars were not significant.

TABLE 7

Performance of two radicole selections (RB25/6/77 and RB10/76/77), two semi-artificial rapes (AR5/7/1 and AR6/1/1) and two rape cultivars, Emerald and Lair, at Threshy Park and Yonderton (Ayr).

	Threshy Park (Pentlandfield)			*Yonderton (Ayr)*		
	Fresh weight kg/plot	*Dry matter %*	*Dry weight kg/plot*	*Fresh weight kg/plot*	*Dry matter %*	*Dry weight kg/plot*
RB 25/6/77	84·5	8·2	6·98	61·8	7·1	4·35
RB 10/76/77	82·8	9·1	7·50	61·8	8·1	4·95
AR 5/7/1	70·5	9·8	6·93	47·8	8·3	4·00
AR 6/1/1	73·0	10·2	7·40	46·0	9·3	4·28
Emerald	77·0	11·3	8·70	45·5	9·9	4·48
Lair	74·3	11·4	8·48	46·0	10·1	4·65
LSD ($P<0.05$)	9·26	1·20	1·161	6·52	0·73	0·678
Coefficient of variation	8·2	8·2	10·36	8·7	5·7	10·4

A number of new *B.oleracea* × *B.campestris* crosses was made but attempts to raise hybrids by embryo culture were relatively unsuccessful, probably due to the genotypes involved and adverse environmental conditions.

Selections were made from three new semi-artificial *B.napus* populations produced in 1976. These are intended for selfing, as the start of a line breeding programme aimed at producing late, dwarf, 'marrow-stem' types of rape. The parents of these populations were artificial rapes, obtained by crossing *B.oleracea* (marrow-stem kales and kohl rabi) with *B.campestris* (stubble-turnips), and leading commercial rape cultivars.

Selections, made in 1977, from a segregating artificial rape, obtained from the Swedish Seed Association at Svalöf, were self-pollinated. The *B.oleracea* parent of this rape was a marrow-stem kale, the *B.campestris* parent, ssp. *nipposinica*. From this material it is ultimately hoped to produce a form combining the high stem edibility of the kale with leafiness derived from ssp. *nipposinica*.

In attempts to introduce new characters into rape (*B.napus*, 2n = 38, aacc) from its parental species *B.campestris* (2n = 20, aa) and *B.oleracea* (2n = 18, cc)

numerous crosses were made in 1974 between diploid and tetraploid forms of the basic species, from which a single allotriploid hybrid (2n = 28, acc) resulted. The parentage of this hybrid was a diploid stubble-turnip and a tetraploid marrow-stem kale (*Ann. Rep. 1974-75,* 15).

The allotriploid hybrid was crossed to leafy rapes and produced progeny ranging in chromosome number from 2n = 32 to 2n = 46. It was hoped to obtain 2n = 38 chromosome plants, basically new *B.napus* forms, but none resulted. Plants with 2n = 36 and 2n = 37 chromosomes were self-pollinated and two 2n = 35, eighteen 2n = 36, sixty-two 2n = 37 and thirty-five 2n = 38 chromosome plants were obtained, (*Ann. Rep. 1977-78,* 35) the majority of these were self-pollinated in 1978 and most produced seed.

Meiosis in PMC's of 2n = 38 chromosome plants was examined by the Cytology Section. None showed completely regular meiosis, bivalent frequency ranging from 16·3 to 18·7 per plant. Multivalent and univalent frequencies were also assessed.

I. H. McNaughton
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CATCH CROPS

Two trials were carried out by the Trials Unit, details are given in Table 8. The entries consisted of Appin and Ballater (leafy, grazing turnips), Civasto and Debra (Dutch stubble-turnips) and Crail (Fodder radish). Perko, a leafy tetraploid form of *B.campestris* derived from ssp. *pekinensis* (Chinese cabbage) and ssp. *oleifera* (turnip rape), was also included. Perko is of German origin and is widely grown there. Being a leafy tetraploid inter sub-species hybrid Perko is thus similar in origin to Appin and Ballater.

TABLE 8

Performance of Appin and Ballater grazing turnips, Civasto and Debra stubble-turnips, Perko (turnip-rape: Chinese cabbage hybrid) and Crail fodder radish, at Threshy Park and Yonderton (Ayr).

	Threshy Park (Pentlandfield)			*Yonderton (Ayr)*		
	Fresh weight kg/plot	*Dry matter %*	*Dry weight kg/plot*	*Fresh weight kg/plot*	*Dry matter %*	*Dry weight kg/plot*
Appin	63·8	7·1	4·53	25·5	7·0	1·80
Ballater	69·5	6·9	4·83	26·0	6·9	1·80
Civasto	59·5	8·3	4·90	24·3	7·6	1·83
Debra	55·3	7·5	4·13	21·3	7·8	1·63
Perko	59·5	7·9	4·65	23·8	7·7	1·83
Crail	63·3	7·0	4·43	23·6	7·0	1·63
LSD (P<0·05)	7·53	0·38	0·64	2·24	0·39	0·18
Coefficient of variation	8·3	3·5	9·6	6·4	3·6	6·8

There were no significant differences ($P<0.05$) between cultivars in dry matter yields in either trial, the high fresh weight yields of Appin and Ballater being counter balanced by their relatively low dry matter contents.

In 1977 GRI, Hurley, carried out a grazing experiment to compare Appin with Canard rape. Low, medium and high grazing pressures were applied. Percentage utilization and organic matter intake were similar for both crops at each stocking rate but, after an initial loss of weight on both crops, live weight gains were superior for rape at each grazing pressure.

F_1 hybrids between various cultivars of Chinese cabbage and a stubble-turnip line (ECD 04), highly resistant to *Plasmodiophora brassicae*, were selfed. Crosses were made between a winter hardy form of the oriental salad vegetable, *B.campestris* ssp. *nipposinica* (cv. Mizuna) and Civasto and Ponda stubble-turnips with a view to improving leafiness.

I. H. McNaughton

Raphanobrassica — An Inter-generic Hybrid Species as a Club-root Resistant Alternative to Rape

Trials carried out at other institutes, over the last three years have provided useful information concerning yields and acceptability to stock as well as levels of toxic factors. Several grazing trials have now been carried out. Seed set of Raphanobrassica was rather better, in 1978, than in recent years.

In 1976, ADAS, in the Northumberland region, made a comparison of the nutritive value of radicole and rape (*cv.* Canard). Yields of metabolizable energy per hectare were similar for the two crops as was their chemical composition. There were no significant differences between the average live weight gain of lambs on the two crops, of 138 and 147g day^{-1} respectively.

In 1977 the West of Scotland College of Agriculture compared radicole with rape at low, medium and high stocking rates. Dry matter yield and utilization at the three stocking rates were similar for the two crops. Average daily live weight gains were slightly higher for rape as was the net carcass production (g kg^{-1} of the dry matter offered).

In 1978 GRI, Hurley compared radicole with Lair rape; both crops gave high dry matter yields of 6·5 ha^{-1} or more, at a series of different sampling dates. The dry matter content of radicole was, however, about three per cent lower than rape, and this could limit the intake of radicole. Percentage utilization of rape and radicole were similar. Some premature flowering was evident in radicole. Live weight gains of lambs were satisfactory for both crops, although higher for rape. There were slight anaemia problems with lambs on both crops but the lambs recovered without a change of diet. Lambs on rape utilized their feed more quickly than did those on radicole. Radicole

showed particularly good regrowth from the first grazed plots and seemed likely to provide more lamb grazing days than rape. Precise details of this trial are awaited.

The Rowett Research Institute, Aberdeen conducted a grazing trial in 1978 of radicole and Appin and Ballater grazing turnips. Appin and Ballater were well utilized by lambs that were finished fairly quickly, putting on satisfactory live weight gains. Lambs on radicole at first accepted the crop but stopped eating temporarily after three weeks and were beginning to lose weight. Grazing recommenced and the lambs put on weight. The plots were sampled at weekly intervals throughout the grazing period for SMCO, thiocyanate, nitrate and nitrite analyses.

In a 1977 trial at RRI radicole was rejected by grazing animals (cattle) until the crop has been frosted, when it was readily accepted. DOMD content and general nutritive value of rape and radicole were similar. In 1978 sheep in pens at RRI were fed radicole (a) freshly cut, (b) 50:50 fresh and frozen, and (c) frozen. In all instances acceptability was quite satisfactory.

SMCO content of radicole expressed as g kg^{-1} of the dry weight was found to be higher than stubble-turnips (including Appin and Ballater), fodder radish and rape cultivars and about equal to Maris Kestrel kale in a 1977 experiment, carried out by The North of Scotland College of Agriculture and RRI. The SMCO content of radicole varied between 4·8 and 6·4 g kg^{-1} DM. Six g kg^{-1} of the dry matter is generally considered to be an SMCO level likely to cause mild haemolytic anaemia. Analyses carried out by SPBS Chemistry Department indicate that the SMCO content of radicole is intermediate between those of its two parents, kale and radish, which are high and low respectively. Further evidence is required and this should be forthcoming from the numerous 1978 experiments, both small plot and field scale, the comparisons being mainly with rape. When analysed, these experiments and trials should also provide further useful information on general performance, best methods of crop husbandry, disease resistance etc.

Small plot trials were conducted in 1978 by the Trials Unit at two sites, Threshy Park (Pentlandfield) and Yonderton (Ayr). Two radicole selections, RB10/76/77 and RB25/6/77, the latter true breeding for flower colour (white), were compared with rape cultivars, Emerald and Lair, together with two semi-artificial rape bulks (see p 47).

The vigour of the radicoles was shown by their higher fresh weight yields than the rapes, this was apparent at both sites, see Table 7, p 47. Dry matter contents of the radicoles were, however, significantly lower ($P<0·05$) than the commercial rapes, as a consequence their dry matter yields were significantly lower ($P<0·05$) than the rape cultivars at Threshy Park. There were no significant differences in dry matter yields between radicoles and rapes at Yonderton.

The lower dry matter contents of radicoles, in comparison with rapes, has been a consistent feature in virtually all trials carried out. The difference has

not always been as high as in the two trials reported here, in which it was as large as three per cent, see Table 7, p 47, Threshy Park results.

Data were obtained from a small trial to compare radicole lines with Lair rape, but interpretation is difficult due to erratic emergence in the radicole plots resulting in plant numbers which were consistently lower than those of rape. The low emergence of radicole seedlings was probably due to poor quality of seed produced under adverse conditions (*Ann. Rep. 1977-78,* 37).

Quantities of seed, obtained from radicoles in isolation plots in 1978, were generally much better than for the two preceding years, although differences between sites as well as plant to plant variation were apparent. Twenty-five siliquae (seed capsules) were sampled from each of a number of plants which had been selected as being reasonably fertile. There was considerable variation, the best plant producing an average of eight seeds per siliqua. Full information on seed yields has yet to be obtained.

As reported last year (*Ann. Rep. 1977-78,* 37), Crail fodder radish failed to pass DUS tests, due to segregation for root colour into reddish-purple and pinkish-red phenotypes. Seed has been produced from plants selected for the latter root colour, known to be recessive, and the progeny should therefore be true breeding. Selection should also result in more uniform flower colour, since root and flower colours are linked.

Diploid and tetraploid *Raphanus sativus* (fodder radish): *R. maritimus* (sea radish) hybrids, back-crossed to *R. sativus,* were selected and multiplied for further selection towards leafy, biennial types. The tetraploid form was used in a number of crosses with various tetraploid forms of *B.oleracea* (kales etc.).

I. H. McNaughton

Breeding for Resistance to *Plasmodiophora brassicae* (causing Clubroot Disease)

Breeders' material was screened for resistance to Plasmodiophora brassicae, *and possible improvements in seedling tests were investigated.*

Inoculum of *Plasmodiophora brassicae* for use in seedling tests was again supplied by Mrs S. Lewis and Dr T. Brokenshire of ESCA. Where possible the populations of *P.brassicae* used in glasshouse tests have been from those of most frequent occurrence in South-East Scotland. In an attempt to overcome some of the inconsistencies which have occurred in previous years, the inoculum received from ESCA was bulked up in uniform conditions using the universally susceptible Chinese cabbage (*B.campestris*) cultivar Granaat. Sufficient infected roots were harvested to supply inoculum for all tests during 1978-79.

Two methods of inoculating seedlings in glasshouse tests were compared. These were (1) the seedling dip method where, seven to ten day old seedlings are dipped in a testing spore suspension before being pricked out; and (2) the slurry inoculum method, where seed is sown directly onto a peat/soil/spore-suspension mixture. Fresh weight per seedling was greater from the seedling dip method ($P<0{\cdot}01$) where seedlings were eight days older than seedlings grown on the slurry inoculum. Root fresh weight, which gave a measure of the mass of infected tissue, was similar from the two methods and hence the ratio of root to total plant fresh weight was greater from seedlings grown on the slurry inoculum ($P<0{\cdot}05$). There are some advantages to both methods, but the use of slurry inoculum is more convenient for routine screening of breeding material and was used in all subsequent tests reported here.

The effect on disease development of growing seedlings of Granaat at 20 mm, 40 mm and 80 mm square spacing was examined using two *P.brassicae* populations and a control treatment (slurry made up with water instead of spore suspension). At harvest, club size increased with increasing seedling fresh weight and with wider spacing ($P<0{\cdot}001$). The ratio of root to total plant fresh weight did not vary with plant density although it was greater from inoculated than from uninoculated plants ($P<0{\cdot}001$). Roots from twenty per cent of inoculated seedlings grown at 20 mm spacing had rotted before they were harvested so that they could not be scored for severity of disease; roots were not rotted on any plants grown 40 mm or 80 mm apart, and the yield of infected tissue per unit area was similar from the two latter plant densities.

Thirteen F_6 lines from the swede breeding programme and the two lines which have been submitted for NLT, see p 35, were tested for resistance to *P.brassicae*. Three of the F_6 lines were resistant to a *P.brassicae* population coded 16-31-31 on the ECD host set and will be tested in 1979 against populations with a wider spectrum of pathogenicity. These three lines were all derived from crosses with the cultivar, Bangholm Wilby. The two advanced lines (SPBS 9939 and SPBS 9943) were susceptible to this population which is known to be pathogenic on most swede cultivars.

Four of the clubroot resistant selections from the swede cultivar Gry were selfed in 1978 and progenies were tested against *P.brassicae* population 20-31-31. Two of the progenies were completely susceptible to this population but 13·0 and 11·1 per cent of plants from the other two progenies were resistant. Four selfed progenies derived from turnip × swede hybrids were tested against the same population. Two progenies from plants with $2n = 37$ had 8·2 and 3·8 per cent resistant plants. The other two progenies from plants with $2n = 38$ chromosomes had 16·7 and 9·4 per cent resistant plants. The resistant plants are being screened by the Cytology Unit for somatic chromosome number of $2n = 38$.

The back-crossing programme to introduce resistance from *B.campestris*, ECD host 04, into oil seed rape was continued (see *Ann. Rep. 1977-78*, 38).

Resistant plants were selfed in 1978 and progenies from the three plants with 2n = 37, and from three plants with 2n = 36 were tested against *P.brassicae* population 20-31-31. Between 37·5 and 70·3 per cent of the progenies were resistant; these plants are being screened by the Cytology Unit for individuals with the somatic chromosome number 2n = 38.

Twelve polycross progenies from the kale breeding programme and ten cultivars were tested for resistance to *P.brassicae* population 16-31-31. All families were susceptible; disease indices based on three categories for disease severity varied from 71·4 to 92·8 per cent in polycross progenies and from 68·4 to 87·5 per cent among the cultivars.

Cynthia J. Williamson

POTATO DIVISION

Breeding Commercial Potato Varieties

Despite a late, cold start in the spring, 1978 proved a successful year for the breeding programme. The crossing programmes produced reasonable quantities of true seed and most intended crosses were successful. The evaluation of resistance to field infection by viruses was particularly satisfactory and confirmed previous estimates of high levels of resistance to leaf roll in advanced clones. The regional trials produced valuable data which augmented those from the Murrays assessment plots. Four clones were submitted for National List Trials. Biometrical studies on mating schemes and trial designs continued. The health of the seed stocks was much improved, compared to 1977, and the low frequency of rogued plants probably indicates the end of the leaf roll epidemic. All stocks of the commercial breeding programme have now been declared free of PSTV. Collaboration with the potato processing industry and growers in the UK and abroad was maintained and extended.

THE 1978 CROSSING PROGRAMME

The overall breeding policy determines the particular attributes which are desired in parents and their progeny and the priority accorded to each. The annual choice of particular parental clones is always difficult, due to the complexity of the data from trials and tests made in laboratory, field and store, which constitute a considerable body of information on many characters for each clone.

When breeding for resistance to disease, which accounted for about 75 per cent of the department's breeding effort in 1978, the origin and level of resistance which is being exploited is a factor affecting the choice of parents. When the breeding work is directed towards intensifying the expression of resistance in an adapted Tuberosum genetic background, as for example in some blight or leaf roll resistance breeding, then the level of resistance will be the principal criterion for the selection of parents. On the other hand, the breeding aim may be to transfer resistance from a wild species or other ill-adapted type as in the use of *Solanum vernei* resistance to *Globodera pallida* or *S. acaule* resistance to leaf roll, into commercially acceptable clones. In this case, greater attention must be paid to agronomic and quality factors as well as to the levels of disease resistance. This need to introduce high levels of resistance of exotic origin without reduction in conventional commercial qualities has inevitably resulted in relatively slow progress in these programmes, but there are clear indications that clones are now beginning to

emerge which are both highly resistant and acceptable in other respects.

In addition to the major effort on resistance breeding, crosses were made for four other projects:—

(i) first-early breeding
(ii) resistance to gangrene (*Phoma exigua* var. *foveata*)
(iii) resistance to tobacco rattle virus (spraing)
(iv) breeding for cooking and processing quality.

VIRUS RESISTANCE

All material in this programme has been bred and selected for resistance to viruses X, Y and leaf roll, from sources of resistance within wild species and Tuberosum from the United Kingdom. These sources were identified initially by tests as being the most promising. By hybridisation and repeated backcrossing to Tuberosum, with culling for susceptibility and selection for commerical qualities, clones come forward year by year with good resistance along with material from other sources, as potential new cultivars.

Resistance to virus Y is an "all-or-nothing" phenomenon and resistant and susceptible genotypes may be readily identified following inoculation of seedlings. (The same is true of virus X.) Resistance to leaf roll is much more difficult to assess since it seems to be relative to the overall level of infection. At high levels, all genotypes of Tuberosum show symptoms of the disease but at lower levels it is possible to distinguish clones having different degrees of resistance depending on the frequency of plants, within each clone, which show disease symptoms. In 1977 250 clones were grown at Broom's Barn Experimental Station, Suffolk, where levels of both virus Y and leaf roll were expected to be high and tubers harvested from this material were grown in trial at Pentlandfield in 1978 for scoring resistance to these two diseases.

Confidence in the resistance rating of clones under test depends on the level of infection achieved in the control cultivars, Pentland Crown and Majestic. The desired level of infection in Pentland Crown, the principal control, is 50 per cent plants infected with leaf roll and one per cent with virus Y. This was achieved in 1977, although, since the infection levels depend on aphid activity, the results are not always so satisfactory (Davidson, *Potato Res.* **16**, 99-108). It should be noted that Pentland Crown is the most resistant cultivar, of those grown in the United Kingdom, to leaf roll and virus Y. It has a rating, on a one to nine scale (susceptible to resistant), of seven for leaf roll and eight for virus Y (*Fmrs. Lflt. No. 3.* Recommended Varieties of Potatoes 1978/9. NIAB. Cambridge). The other control, Majestic, showed approximately ten per cent less leaf roll infection than expected. One feature of the trial was that ten clones which previously had zero readings for leaf roll infection in the 1975-76 trial were confirmed as being very resistant (Table 9). Of these clones some have already been used as parents and three are currently in an advanced stage of selection. Of the 250 clones tested in 1977-78 eleven scored zero infection and will be again in trial in 1979-80.

TABLE 9

Infection rates in a confirmatory trial 1977-78 for ten clones provisionally classed 1975-76 as leafroll (and virus Y) resistant.

Clone	*Number of plants infected with leafroll and/or virus Y out of:—* 36 exposed LR	Y	60 exposed LR	Y	% of plants infected with LR	Y
G6246(6) and G6249(6)	0	0			0	0
G6237(2) and G6281(2)	1	0			3	0
G6282(6)	2	0			6	0
G6246(8)	3	0			8	0
G6214(2)	4	0			11	0
G6240(3)	5	0			14	0
G6241(3) and G6183(8)	6	0			17	0
Pentland Crown			34	1	51	1
Majestic			37	12	62	21

EELWORM RESISTANCE

The development of a winter screening technique for potato cyst nematode resistance (*Ann. Rep. 1977-78,* 54) has enabled the selection of resistant material at an earlier stage. Some of the material which had been bred for eelworm resistance and which had been grown in single-tuber plots in 1977 was tested during the winter of 1977-78 to aid in selection for eelworm resistance amongst the same clones grown in three-tuber plots in 1978. This winter, 1978-79, it is hoped to test tubers from a proportion of the glasshouse grown seedlings.

QUALITY

The routine screening has continued with 3,000 clones being tested for cooking and crisping quality. Modifications in crisping assessment have been introduced. One is the production of a crisp colour chart, on which colour is scored on a one to eight scale permitting easier comparison between clones and against the standard cultivar, Record. Changes in the crisping method have reduced by one-third the time taken to crisp a batch of clones.

Clones for testing (1978-79) were stored in a controlled environment chamber at 10°C. Samples of the Regional Trials clones were, in addition, stored at 5°C. The object of this is to study the effect of different temperatures, during prolonged storage, on crisping quality.

TRIALS AT THE MURRAYS

A cold and wet spring delayed planting at the Murrays. The late planting was followed by a prolonged drought. Planting of the first-early plots was delayed by about four weeks and they suffered much more than the main crops from the drought. The main crops grew well and gave a reasonable

yield. Pentland Crown, one of the controls, was used as a "blanket" control with one plot to every fourteen plots of the clones in the assessment trials. The average yield of Pentland Crown was 24 kg (twelve plant plot) with a range of 17 kg to 29 kg. About eight hectares were required to accommodate the Breeding Department's material at the Murrays. The harvest was completed in a relatively short time because of the good weather.

1978 REGIONAL TRIALS

Nineteen seventy-eight proved a good year for assessment of our advanced clones at the various trial sites in England, Wales and Scotland. With the exception of the Welsh first-early sites, where seed tubers produced in Radnor (as opposed to Blythbank) were planted, the incidence of leaf roll virus was very low and did not affect the interpretation of the data. At the Welsh sites there was obviously some carry over from the 1976 leaf roll epidemic, but this should now have been eliminated as fresh, disease-free stocks were grown in 1978 for trials planned for 1979.

Twelve advanced SPBS first-early clones and six commercial varieties were grown in replicated trials at four sites: Trefloyne, Pembrokeshire; Penrice, Gower; Stranraer, Wigtownshire; and the Murrays, East Lothian. The cold, wet start to the year delayed planting until early April at the former three sites and until 8th May at the Murrays. However, despite this late start the trials grew well and were lifted during the period 20th June to 13th July.

Clones 8906abc(11) and 7169(10) continued to perform well and the decision was taken to submit them for Plant Variety Rights and to enter them for National List Trials in 1979. Three other clones, 8893abc(35), 9114cc(2) and 9869a(9) showed promise and will be in regional trials again in 1979.

Nine clones have been identified as candidates for 1979 regional trial assessment and seed-tuber samples have been supplied to Dr E. Allen of University College of Wales, Aberystwyth, to produce acclimatised seed of the more advanced of these for trial in South Wales in 1980.

Eighteen SPBS clones and three commercial controls were included in the 1978 principal maincrop regional trials. Clone 8990(7) performed outstandingly. The assessment of yield of second early maturity clones such as 8990(7) is complicated by the fact that lifting dates of second early varieties can be somewhat arbitrary in agricultural practice and a degree of flexibility is necessary. This clone seems to be capable of providing an attractive marketable yield fairly early in the season and higher than average yield at full maturity. To augment our data on this clone, it will be included in our early trials in 1979. A sample has also been sent to PBI, Cambridge, where along with two other advanced second early selections, 8990(7) will be grown in a two-lift trial at each of two sites and compared with control cultivars such as Estima. This is the first attempt to co-ordinate the trial system of our pre-NLT and NLT submissions with those of PBI and further co-operation is proposed.

Clone 7495(6) performed up to expectations. Though generally accepted as equivalent to Pentland Hawk in yield, it equalled Pentland Crown at Arthur Rickwood EHF.

Of the remaining sixteen clones in the trials, three performed sufficiently well to justify re-entry in the 1979 maincrop trials and two will be included in the second early trials mentioned above.

In addition to the principal trial described, a series of unreplicated observation plots of less advanced clones was also grown at each of the English sites. Availability of seed, land and the logistics of this enterprise restricted this to 36 clones, plus six controls, in small plots of six plants. However, the information gained proved most useful and the better clones will be entered in the replicated trials planned for 1979.

SEED PRODUCTION

The spring weather delayed planting at Blythbank and nearby sites on Bordlands and Drochil Castle farms until the beginning of May. However, subsequently ideal conditions encouraged fast growth and roguing was begun ten days earlier than in the previous two years. The stocks were found to be very healthy probably because of efficiency of roguing in 1977 and the intensive spraying regime.

The last of those clones which had not been tested for PSTV were grown at Drochil Castle. These were sampled during the season and all results from DAFS were negative. All clones at the multiplication sites will now be clear of suspicion of PSTV infection.

Four stocks intended for NLT submission received Approved Stock Certificates from DAFS.

Stocks at Bordlands reached seed size unusually early and were burnt down by 2nd August. With the exception of the single-tuber plots, Blythbank and Drochil Castle were burnt down a week later.

The single-tuber plots were hand dug as usual. All the other plots were harvested using the one-row and two-row 'Famos' machines.

Lack of space at Blythbank necessitated the storage of the produce of the three-tuber plots at Sourhope (HFRO) and the sixteen-tuber plots at the Murrays. This problem will be alleviated when the additional Blythbank store, now under construction, is completed.

Meristem culture continues to be used to free genetically valuable clones from systemic virus infection.

SUBMISSIONS TO NATIONAL LIST TRIALS

As a result of the changes introduced into the regional trials procedure (*Ann. Rep. 1976-77*, 37-8) an unusually large number of clones in an advanced stage of selection and evaluation, has accumulated in the trials system. Sufficient data have been obtained on four of these clones to enable them to be

submitted for statutory trials to be grown in 1979 and 1980. These clones are described below.

Clone 8906abc(11) is a true first-early with attractive pink-eyed tubers consistently out-yielding currently grown cultivars. Amongst its attributes is a measure of polygenic resistance derived from *S. vernei* to the British pathotypes A, B and E of potato cyst nematode.

Clone 7169(10) is another first-early with a record of outstanding early yield performance since 1971. As well as having good table quality, processors' trials have demonstrated some potential for crisping.

Clone 8990(7), a second-early, produces a highly attractive ware sample with very good cooking and crisping quality. It has consistently out-yielded Maris Peer and has equalled Pentland Crown when lifted at maturity.

Clone 7495(6) has consistently been rated equal, or superior to, Record in industrial processors' crisping trials. White-fleshed, with regular oval tubers, it is of similar maturity to Record and has the same level of resistance to virus Y and leaf roll as Pentland Crown. It also possesses good resistance to blight.

BIOMETRICAL WORK WITH POTATOES

The thirteen parent incomplete diallel cross (*Ann. Rep. 1977-78,* 60) was grown in a randomised block design at the Murrays. After harvest the produce was scored for weight and number of tubers in the chat and ware size categories, and for the degree of cracking. Analyses of these data will permit the genetical variation of the characters to be partitioned into that due to general combining ability and that due to specific combining ability, which will provide guidance on the choice and combination of parents for the future.

Three uniformity trials were grown during the year. A plot of the first-early cultivar Epicure was grown in Wigtownshire and plots of the maincrop cultivars Pentland Crown and Croft were grown at the Murrays. From each, 625 plants from a 25 × 25 grid were individually hand dug. The produce was graded, weighed and counted. These studies should indicate the size and shape of plots in variety trials which will give optimum efficiency.

In studies on the need for guard (or discard) rows on the edges of plots four cultivars, King Edward, Majestic, Stormont Enterprise and Pentland Hawk were grown in single-row, six-tuber plots; each plot of each variety being surrounded by fourteen plants of one of the other varieties, in all of the sixteen possible combinations. (This type of design is sometimes called a "competitive" or "mechanical" diallel.) The trial was grown in five replications. After harvest yield components and specific gravity were measured. It is hoped that analysis of these data will confirm the preliminary work, reported last year (*Ann. Rep. 1977-78,* 61) suggesting that the absence of guard rows (as in our regional trials) is not a factor likely to prejudice comparisons between varieties. During the year a PMB financed research student, Mr W. Fielding, began his PhD work in Edinburgh. Mr Fielding will be working both in the

Department of Statistics at Edinburgh University and at SPBS on the design of potato variety trials. In anticipation of his arrival a trial of nine cultivars at three different spacings was planted. Each plot consisted of four rows, each of which was harvested and scored separately. This allowed comparison of the analyses in which (a) data from the two outer rows were discarded and (b) in which all the data were included. No obvious gain in precision was secured by omitting data from guard rows. Although statistically significant differences between varieties and between spacings were detected, no significant interaction between varieties and spacing was detected.

Analysis continued of data from the 1977 uniformity trial of the cultivar Corrie. In this trial twelve per cent of the plants showed symptoms of infection with leaf roll virus which rendered it unsuitable for its original purpose. Nevertheless, valuable data on the effect of this virus were obtained. The leaf roll infection reduced the yield of plants. Diseased plants were unaffected by the health status of neighbouring plants. However, the weight of ware tubers produced by healthy plants was affected by the health status of their four immediate neighbours such that their yield increased proportionately to the number of infected plants surrounding them. This yield compensation is attributed to the reduced competition for light, water and minerals offered by diseased plants which allows healthy plants a more favourable local environment in which to grow. Further consideration of the nature of yield compensation suggested that percentage yield loss would most appropriately be described by the expression

$$\frac{100p(F - A) - 4p(1 - p)(\Delta_H - \Delta_D)}{F}$$

where p = the overall frequency of infection, F and A are the mean yields of the centre plants of pentads of the type $H\begin{smallmatrix}H\\H\end{smallmatrix}H$ and $D\begin{smallmatrix}D\\D\end{smallmatrix}D$ respectively, (H represents a healthy, and D a diseased plant) and Δ_H and Δ_D are the respective changes in yield of the central plant in a pentad caused by the change in health status of one plant in the surround.

COLLABORATION

1. *Industrial processors*

Interest in new and potential SPBS varieties for processing continues to be shown by the industry. New contacts were made and the established ones continued throughout 1978 and seed and ware samples were supplied to several of the collaborators cited in this report (pp 18-20). For example, small samples of the produce of the main crop trials were supplied to McCain International Ltd. (frozen french fries) and Golden Wonder Ltd. (crisps), for small scale assessment. The data will be used to supplement those of our own quality testing laboratory. Meetings with the Potato Processors Association Technical Group were held and more are planned to ensure that this collaboration continues and to maximise its benefits.

2. *Overseas*

As a result of a visit to the station by Dr H. Carlsson of the Swedish University of Agricultural Sciences, Uppsala and Dr N. Gustafsson of IVK Potatis AB, hundred-tuber samples of ten advanced clones were sent to Sweden for multiplication and trial, including four NLT submissions. It is hoped that some will prove to be adapted to climatic conditions in Sweden.

In a small scale trial of ten advanced clones conducted at two sites in Spain, in collaboration with Luis Matutano SA, three showed considerable promise for early production. The clones 8990(7), 8906abc(11) and 8974ab(16) have now been planted in replicated trials at two sites, one near Valencia on the mainland and one in Majorca. A further ten clones are being grown in a preliminary trial.

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Potato Virus Resistances

The project includes testing breeding material for resistance to potato viruses X, Y and leaf roll and the spraing viruses (mop-top and tobacco rattle viruses).

Work has started to try to prepare antisera against potato virus Y and leaf roll and mop-top viruses to permit routine serological tests to be made for these pathogens.

All potato material kept for virological purposes, other than breeding, was PSTV tested in 1978. This includes plants of *Solanum demissum* for virus Y testing, virus-infected or susceptible material for grafting, museum collections of virus infected plants and those known to contain resistance genes, and also progenies of experimental crosses.

FIELD TRIAL FOR RESISTANCE TO POTATO LEAF ROLL VIRUS AND POTATO VIRUS Y

In a field trial, grown at Broom's Barn Experimental Station (Suffolk) in 1977, 344 clones were interspersed with infector plants. Tuber progenies from this trial were grown at Pentlandfield in 1978 and scored for infection with leaf roll and virus Y. Infection levels were quite satisfactory, particularly for leaf roll (Table 9, p 56), and it was possible to identify several clones that showed promise with respect to leaf roll resistance.

SCREENING FOR RESISTANCE TO POTATO VIRUSES X AND Y

About 13,500 seedlings from 80 progenies produced by crossing clones resistant to virus X or Y or both were spray-inoculated with these viruses at

the cotyledon stage to permit the elimination of susceptible plants. Tubers from 6,264 of the survivors were passed to the Potato Breeding department for further selection and multiplication.

Another 850 clones were screened for X and Y resistance by sap-inoculation of plants grown from tubers, and 137 advanced clones were screened in more detail, by graft inoculation with the B and common X strains and the A, C, VN and common (Yo) Y strains as well as sap-inoculation with Yo.

TESTING FOR THE PRESENCE OF VIRUSES X AND Y

Some plants were tested for the presence of viruses X and Y before and after meristem culture, and some leaf samples from Drochil Castle were tested so that virus-infected plants could be removed. Out of 166 bulks each of four plants tested, eight were found to contain Y but none was found to contain X.

THE SPRAING VIRUSES

Tobacco rattle virus (TRV)

There were two trials for TRV resistance in 1978; the main one at Tayport (Fife) and a supplementary one at Sherriff Hutton in Yorkshire. At Tayport, 109 clones from the breeding programme and sixteen named varieties were grown in an infested field; at Yorkshire eighteen of these clones and six of these varieties were grown. After harvest the incidence of symptoms (spraing) in the tubers was scored.

In the Yorkshire trial there was a little spraing: zero to eleven per cent of the tubers were affected in sub-plots of the susceptible control variety Pentland Dell. The spraing was nearly all at one end of the plot. This is consistent with the results of tests on soil samples taken at planting, though tests on soil samples taken in July showed that all parts of the plot contained TRV. Five clones could be identified as susceptible, but the others cannot be taken as definitely resistant.

Spraing scoring for the Tayport trial is as yet incomplete, but the results so far look the best for some years. Extensive soil testing before planting permitted a plot to be chosen with a high and fairly uniform incidence of viruliferous nematodes (*Trichodorus* spp), and the weather was apparently more favourable for infection than in recent years. In 30 sub-plots of Pentland Dell scored so far, the incidence of spraing ranged from zero to 75 per cent, and only four of these sub-plots had no spraing.

Potato mop-top virus (PMTV)

In the 1977 PMTV resistance trial, 213 clones were grown in an infested field at Braco (Perthshire). After harvest the tubers were scored for spraing, and sixteen tubers from each sub-plot were grown on and scored for haulm

symptoms at Pentlandfield in 1978. Although soil tests made in 1977 showed PMTV to be present, there were few spraing or haulm symptoms even in the control cultivar, Arran Pilot, which is known to be susceptible to the disease. Three clones were clearly susceptible, with spraing in more than twenty per cent of the tubers.

In the 1978 trial, 96 clones plus sixteen named varieties were grown at Braco. The tubers have not yet been scored for spraing, but there is at least some infection with the vector *Spongospora subterranea* (corky scab) and some spraing in the susceptible control variety, Arran Pilot.

APHID COUNTS

An aphid survey was made in the potato field (Longriggs) at the Murrays in 1978, at fortnightly intervals from 14th June to 9th August. The first sampling date was before spraying began, the second was twelve days after demephion treatment and the rest were five days after each spraying with pirimicarb. At each sampling, 50 plants were examined. No potato aphids were found until July, and the most (30) were found on 9th August, all alate *Macrosiphum euphorbiae*.

R. M. Solomon
I. B. Majewicz

Potato Blight Resistance

Selections from the commercial breeding programme were assessed for foliage and tuber resistance to blight, in glasshouse and field trials. The effect of the age of tubers on inoculation was investigated further, and a glasshouse test for tuber blight assessment developed.

FOLIAGE BLIGHT (*PHYTOPHTHORA INFESTANS*)

The foliage resistance of 568 fifth- and 122 sixth-year selections from the commercial breeding programme, of 106 Neo-Tuberosum clones and of 29 dihaploids and dihaploid/tetraploid crosses was assessed in glasshouse tests on whole plants. The percentage of selections which scored six or more on the one to nine scale of increasing resistance is shown in Table 10.

TABLE 10

Levels of foliage blight resistance in breeders' selections.

	Number of clones scored	*Number of clones scoring ≥ 6 (1-9 scale)*	*% of total*
Breeders' selections			
Commercial programme			
5th year	568	125	22
6th year:—			
Clones from blight resistant parents	25	6	24
Clones from other crosses	97	7	7
Neo-Tuberosum clones	106	24	23

Leaflet-test results from 1977 were confirmed in two tests on whole plants, for twelve dihaploids of blight-resistant tetraploids, and a high level of resistance was shown by four of nine clones derived from a dihaploid of Pentland Crown crossed with a PCN-resistant tetraploid. In a detached leaflet-test, 33 of 205 diploid mass-selection clones obtained a score of six or more on the one to nine scale.

Seedlings of 225 progenies bred for foliage resistance were screened and 131 progenies showed a high level of resistance.

TUBER BLIGHT (*PHYTOPHTHORA INFESTANS*)

The routine laboratory test for assessing tuber resistance was carried out on fifth- and sixth-year selections from the commercial breeding programme. The percentage of early clones obtaining a score at least as high as the resistant control variety, Wilja, is shown in Table 11. However, the level of infection in maincrop clones was too low to allow other than very susceptible clones to be identified.

TABLE 11

Levels of tuber blight resistance in commercial breeding selections.

	Number of clones scored	*Number of clones equal to or better than Wilja*	*% of total*
5th year of selection	150	72	48
6th year of selection	30	19	63

Three out of six diploid clones were more resistant than the control varieties Pentland Crown and Record, and previous years' results for three dihaploids of Pentland Crown were confirmed.

Delaying inoculation of tubers after lifting, for between one and four days, did not reduce the numbers of blighted tubers, contrary to the findings in 1976 and 1977 (*Ann. Rep. 1976-77*, 48; *Ann. Rep. 1977-78*, 51). As in 1977, 50 tubers of each of ten maincrop varieties covering a range of susceptibilities, were lifted and inoculated on five occasions at fortnightly intervals during August and September. In the two varieties in which infection levels were sufficiently high for a trend to be observed, susceptibility decreased as lifting was delayed. Ten varieties were treated similarly between mid-July and mid-September. Infection levels were generally higher at the first two than the last three harvesting dates, those at the latter being similar (32, 30 and 29 per cent respectively compared with 58 and 73 per cent in July and early August). However the blight susceptibility of Pentland Javelin remained above 70 per cent at each harvesting date.

The effect of small variations in inocula concentration on test results was investigated in an experiment in which duplicate boxes of eight early varieties were sprayed with a zoospore suspension containing $0{\cdot}75 \times 10^4$, $1{\cdot}5 \times 10^4$ or 3×10^4 spores ml^{-1}; (i.e. a range of half to twice the normal concentration).

The overall level of blight did not differ between treatments. This observation was extended by spraying maincrop varieties likewise with concentrations between $0{\cdot}4 \times 10^4$ and 6×10^4 spores ml^{-1}; only at the lowest concentration was there some reduction in the subsequent amount of blight.

Advanced clones from the commercial programme were assessed in a field trial at Yonderton Farm in Ayrshire. The overall level of infection was low, only ten of 126 clones having more than ten per cent of tubers (mean of two five-tuber plots) infected. Six of these clones had been laboratory tested in 1976 and five were also susceptible in that test. Good agreement was obtained between the tuber blight scores for ten of eleven clones tested in Ayrshire in 1977 and 1978. No useful foliage blight observations were made in 1978 since the epidemic progressed rapidly between two visits made at an interval of thirteen days, and all clones were severely infected by the time of the second visit.

The comparison of the blight resistance of Croft with Majestic at three sites in South Wales yielded very low levels of tuber blight, when harvested in late September 1978, in spite of the foliage having been previously infected.

In 1977 tubers were taken from progenies of 39 proven blight-resistant × putative blight-resistant parents, under multiplication in their fourth year of selection at Blythbank, and the blight reaction of each progeny assessed. Ten of these progenies were further examined in 1978 by *in vitro* blight tests on 25 tubers of ten individuals in each progeny. In spite of a low level of blight in 1978 the five progenies picked out as resistant in 1977 were again resistant in 1978, as were two other progenies which had showed low levels of infection in 1977. Two of three 1977 susceptibles were susceptible when re-tested.

Another method of searching for tuber blight resistance at an early stage of selection would be to examine the resistance of tubers produced, in pots, by seedlings. Small tubers, similar in size to those produced by seedlings, were obtained by planting chat-sized mother tubers of the varieties Bintje (resistance category one), Record (category five) and 7495(6) (category 9) were planted in five-inch pots in June 1978, and the tubers of ten plants of each variety washed from the pots when the foliage had matured. They were inoculated and stored for five weeks. The percentage of tubers infected was 100, 76 and eight respectively. Less infection was obtained when the tubers were removed at flowering or if the soil was drenched with inoculum *in situ*.

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R. L. Wastie

Potato Tuber Disease Resistance

Routine disease screening was carried out against gangrene, skin spot, common scab and dry rot. Improvements to test technique and the possibility of soft rot screening were also investigated.

GANGRENE (*PHOMA EXIGUA* VAR. *FOVEATA*)

In the winter of 1977–78 gangrene tests were conducted on about 520 clones from the commercial and strategic breeding programmes. The high proportion of resistant clones among the commercial breeding material, reported last year, was also apparent this year, for 132 of 224 newly-tested fifth-year selections fell into the two resistant categories of seven and nine on the five-point scale which used only the odd digits 1, 3, 5, 7 and 9 (*Ann. Rep. 1977-78,* 51). Results of the standard cornmeal-sand inoculation test compared between two successive years were in satisfactory agreement, for only 27 of 209 clones tested in both years differed by more than one category on the five-point scale. The number of tubers tested per clone in the first year of testing, was reduced from twenty to ten, but it is still possible to identify, and hence discard, highly susceptible clones at this stage of selection.

Further investigation of the effect of moisture on the development of gangrene has confirmed the importance of an initial period of high humidity; tubers of Pentland Crown surface-inoculated with a cornmeal-sand culture were held at 100 per cent relative humidity at 4°C for one, two or four weeks before being transferred to 80 per cent humidity at the same temperature. The gangrene score (the mean of three boxes of twenty tubers per treatment, scored on a scale of 0–24 by McKee's method (*Pl. Path.* **12**, 106–9) was 3·5, 3·0 and 5·2 respectively at the end of the experiment, which lasted eleven weeks. Tubers held throughout at 80 per cent relative humidity had a mean disease score of 0·3.

A comparison was made between 4°C and 8°C as incubation temperatures for gangrene. Three boxes of each of six varieties were incoculated and held for eleven weeks at each temperature. The overall mean disease score was 5·8 at 4°C and 7·5 at 8°C, with the relative order of susceptibility between varieties being similar at both temperatures.

Tubers of eight varieties were lifted at three-week intervals, from 28th July until 21st October, inoculated in late November and scored eleven weeks later. As expected, mean disease scores decreased throughout the season, from 3·7 overall in July to 1·6 in October, but the relative positions of the varieties in order of increasing resistance changed somewhat, Home Guard and Pentland Hawk being relatively more susceptible at the earliest lifting date.

SKIN SPOT (*POLYSCYTALUM PUSTULANS*)

Although 300 sixth- and seventh-year clones were tested for their susceptibility to skinspot in 1977–78, only 42 were sufficiently severely infected, again with natural infection, to be regarded as susceptible. Seventeen of these had been similarly noted as susceptible the previous year, a further seven had some degree of infection, but eighteen were not susceptible previously.

The repeated failure of artificial inoculation is not due solely to the lack of surface sterilisation of the tubers, as work during the winter of 1978–79 has demonstrated. Eight boxes each of twenty tubers of the variety Record were lifted five days or one day before inoculation, and a further set of eight boxes of the latter treatment was stood in water overnight (eighteen hours) in an attempt to soak the lenticel tissue in order to facilitate the entry of the fungus. Half the tubers from each treatment were surface-sterilised in two per cent formaldehyde solution, and thoroughly washed before being inoculated with culture macerate and incubated for eighteen weeks at 4°C at 100 per cent relative humidity. Mean disease scores, on the scale of 0-24, are shown in Table 12. Tubers lifted five days before inoculation had very little infection,

TABLE 12

Effect of storage and sterilisation on development of skin spot. Mean disease scores from four boxes of twenty tubers per treatment.

	Sterilised	*Not sterilised*
Tubers lifted five days before inoculation	1·5	1·4
Tubers lifted one day before inoculation	8·1	4·6
Tubers lifted one day before inoculation and soaked overnight	15·1	3·2

in spite of sterilisation, whereas those inoculated within 24 hours, especially after overnight soaking, were extensively infected. Tubers in the routine skin spot tests in the winter of 1978–79 were inoculated the day after lifting, and most clones were severely infected as a result.

COMMON SCAB (*STREPTOMYCES SCABIES*)

As reported last year, the Archerfield (East Lothian) plot, where a sandy soil of high pH favours the disease, was used only for scab tests of fifth-year material in 1977. Fifty-one per cent of 229 selections were assigned to the top two categories of resistance on the standard five-point scale. Results of the scab trial of sixth- and seventh-year clones under polythene tunnels at the Murrays were disappointing in that the level of scab was generally low, and the most highly susceptible standard varieties (Maris Piper, Majestic and Pentland Glory) had less than 25 per cent of their tubers infected over at least one-eighth of their surface. Altogether, 25 clones (of 370 planted) were identified as very susceptible, with more than twenty per cent of their tubers infected. Sixteen of these clones had been assessed in 1976 at Archerfield;

eleven were susceptible, four intermediate and one apparently resistant at that time. One of the highly susceptible seventh-year clones was very susceptible also in regional trials at Gleadthorpe EHF in 1977 and 1978.

In view of the impending loss of the Archerfield site in a few years time, since the Forestry Commission is replanting the area, scab testing was reorganised in 1978. A new site was offered on Scoughall farm near Whitekirk, East Lothian, and run in parallel with Archerfield. The Murrays scab trial under polythene tunnels was used for fifth-year material, with the intention of identifying only the most highly susceptible clones. The remaining material was planted, in larger plots than hitherto, at the Archerfield and Scoughall sites.

DRY ROT (*FUSARIUM SOLANI* VAR. *COERULEUM*)

During the 1977–78 season, three methods of wounding tubers (by cutting in half, scraping the surface with a nail board, or by punching with a glass rod to a standard depth) were compared, followed by inoculating either by dipping in culture macerate or rolling in a cornmeal-sand culture, and incubating for three weeks at 4°C followed by four weeks at 15°C. The glass rod method of wounding, followed by rolling in cornmeal-sand, gave the best separation between resistant and susceptible varieties, and permitted the identification of those which were susceptible (Catriona, Arran Pilot, Dunbar Standard, and Record), but failed to recognise Suttons Foremost as being more resistant than other moderately resistant varieties. An experiment to investigate the effect of inoculating the cut surface of halves of tubers and incubating them for zero, one, two or four weeks at 4°C before transferring them to 8°C or 15°C for the remainder of the four-week period of the experiment showed that with both Record and Pentland Crown the intensity of infection decreased as the period at 4°C increased. No difference was detected in the development of dry rot at 8°C and 15°C.

The first routine dry rot test of twelve standard varieties and 28 sixth- and seventh-year selections (chosen because of their potential use as crisping varieties) using the glass rod as the means of damaging the tubers, followed by inoculation and then incubation for two weeks at 5°C and seven weeks at 15°C, gave generally low levels of infection. Of the eight standard susceptible varieties, only two, Maris Piper and Catriona showed any appreciable dry rot. One of the clones was considerably more susceptible than was Maris Piper but more experience must be gained of dry rot testing before the results can be regarded with confidence.

WART (*SYNCHYTRIUM ENDOBIOTICUM*)

Twenty-four of 29 virus-resistant clones submitted to DAFS for testing in 1977–78 were found to be completely or partially resistant to wart. Only seventeen clones from the commercial breeding programme were submitted.

twelve first-early clones (four tubers of each) and five advanced selections (ten tubers of each). Eight of these clones had been tested the previous year, but only three of them gave the same result in both years. Two of the susceptibles had previously been rated as resistant and three resisters were recorded in both the resistance grades RG1 and RG2 as described by Pratt (*EPPO Bull.* **6**, 111-7).

SOFT ROT (*ERWINIA CAROTOVORA* VAR. *ATROSEPTICA*)

Exploratory work on the development of a method of screening advanced clones for susceptibility to soft rot was begun during the winter of 1978-79 with assistance from Mr R. A. Cheatle, a sandwich-course student from Lanchester Polytechnic (Coventry). Useful preliminary discussions were held with colleagues at the Food Research Institute and the Scottish Horticultural Research Institute.

R. L. Wastie
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Potato Cyst Nematode Resistance

Four hundred and seventeen clones were screened for partial resistance to Potato Cyst Eelworm using traditional methods allied to new experimental design and extensive use of the computer. Over 1500 clones were also screened using the New Zealand closed container technique.

In 1978 the standard glasshouse resistance tests were carried out on newly constructed benches ensuring a flat surface and hence less variable moisture levels. Three hundred and forty clones derived from *Solanum vernei* and *S.andigena* were screened for resistance to *Globodera pallida* and 77 of these were also screened for resistance to *G.rostochiensis*. The cool summer favoured good plant and root growth with a large number of cysts developing on the control, Pentland Crown. This work was carried out using trial layouts based on the α-designs of Patterson *et al* (*J. agric. Sci., Camb.* **90**, 395-400). In these designs each replication (superblock) is divided into blocks. The blocks were arranged with their long axis along the length of the bench. In some experiments block effects were significant due to a lower number of cysts on plants in the block at the front of the bench. While there is no obvious reason why this should happen our experience this year suggests that there is a real benefit in using incomplete block designs of this type.

A study of the possibility of genotype × environment (G × E) interactions in glasshouse tests was carried out on two sets of eleven and eight clones derived from *S.vernei*. Analysis of the data collected in 1975, 1976 and 1977 by the method of Finlay and Wilkinson (*Aust. J. agric. Res.* **14**, 742-56)

showed the presence of significant G × E interactions. Further, there was a linear relationship between the regression slope and phenotypic means of *S.vernei*-derived material. The control cultivar, Pentland Crown, did not however conform to this pattern. Thus the apparent changes in the levels of resistance from year to year (expressed as a percentage of Pentland Crown) or in rankings can be accounted for and are not due to inadequacy of the testing system.

The container method of Foot (*N.Z. J. Zool.* **4**, 183–6) has been further developed for mass-screening. The effects of potting media, moisture levels, methods of inoculation, effect of sterilisation and time of scoring the white cysts of *G.pallida* have all been examined. A procedure has now been adopted using sterile sand and inoculation with an egg suspension of 2500 eggs/container at the time of planting. A moisture level of ten per cent appears to be optimal and white cysts are counted seven to eight weeks after planting, the canisters having been stored at 20°C in the dark.

Initial results indicate that there is a good correlation between counts made through the transparent container walls and total cyst counts ($r = +0{\cdot}76\ P < 0{\cdot}001$). Comparison between this method and the standard glasshouse root ball technique again indicates significant agreement ($r = +0{\cdot}98\ P < 0{\cdot}01$). A wide range of material is under test to confirm this.

Before this work began, 1580 clones in their third year of selection were screened in closed containers using John Innes No. 2 compost inoculated with cysts to give 40 eggs gm^{-1} air dried soil. This has enabled breeders to take resistance to potato cyst eelworm into account when assessing material at an early stage in the breeding programme. Nine hundred and fifty of these clones were the product of a partial diallel involving 24 parents derived from *S.vernei* and representing 107 progenies. General and specific combining abilities (GCA and SCA) were derived from the data, which were analysed by the method of England (*Theor. appl. Genet.* **44**, 378–80). Both GCA and SCA effects were significant and of equal magnitude (Table 13). It appears that

TABLE 13

Analysis of variance of number of cysts counted.

Source	*df*	*Mean Squares*
Between progenies	106	3078·28***
General combining ability	23	3259·08*** $\sigma^2_{GCA} = 78{\cdot}18$
Specific combining ability	83	1642·63*** $\sigma^2_{SCA} = 77{\cdot}38$
Within progenies	949	993·71

***$P<0{\cdot}001$

parental phenotype is a poor guide to parental value. Tests on seedlings showed that significant differences in resistance between progenies could be detected and that GCA and SCA effects were also significant. GCA effects were greatest between susceptible parents.

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L. A. Wilson

Aspects of Potato Cyst Nematode Biology

Studies on hatching of Globodera pallida *and its ability to invade potato roots suggest that juveniles have difficulty either in locating or in invading the roots of some clones derived from* Solanum vernei. *An investigation of diapause in* Globodera rostochiensis *is in progress.*

Tests on the hatching response of *Globodera pallida* to clones of *Solanum tuberosum* and *S.vernei* × *S.tuberosum* were continued. Investigations were begun on the rate of invasion of the roots of this material by second-stage juveniles (the currently accepted term for immature PCN, the word larvae having been used in the past). One of the *S.vernei* × *S.tuberosum* clones, 8917b(3), which in three preceding years had given cyst counts about ten per cent of those of Pentland Crown (when tested against pathotype E of *G.pallida*) was examined for its ability to promote hatching compared to the cultivar Home Guard, which had previously been shown to produce a very active root diffusate (*Ann. Rep. 1977-78,* 54-55). Root diffusate was prepared at intervals of one, two and three weeks after planting and three doses were applied to cyst batches at weekly intervals. The percentage hatch from 8917b(3) and Home Guard was about the same (86 per cent and 80 per cent respectively). Sprouts of the two clones were grown in infested soil (40 eggs g^{-1}) for three weeks. Roots were lifted, washed, weighed and stained with cotton blue. The number of juveniles of *G.pallida* per gram fresh weight of root was 35 per cent lower in 8917b(3). Development was also slower. In a further experiment the number of juveniles g^{-1} fresh weight of roots was about 70 per cent lower in 8917b(3) than in Dunbar Standard ($P<0{\cdot}01$). Further work is in progress to confirm these results, which tend to support the findings of Williams (*Proc. Linn. Soc. Lond.* **169**, 93-104) that invasion of *S.vernei* by juveniles is reduced.

Up till now only a few *S.vernei* × *S.tuberosum* clones have been available in sufficient quantities for research work. To extend the range of material available for study, sixteen clones have been cleared of virus Y and leaf roll by heat treatment followed by excision and culture of meristems. Six of these clones are fourth generation derivatives of *S.vernei* × *S.tuberosum* crosses, chosen because of their resistance to potato cyst nematode and their desirable agronomic qualities. Dihaploid seed has also been obtained from some of these clones in collaboration with the Potato Strategic Breeding Department.

During the winters of 1975 and 1976 tests intended to measure the resistance of clones to *G.rostochiensis* failed because no new cysts were produced. It has been suggested by Shepherd and Cox (*Ann. appl. Biol.* **60**, 143-50) that eggs of this species undergo a seasonal diapause, but the results of Ellenby (*Ann. appl. Biol.* **43**, 1-11) do not support this. Studies designed to indicate whether diapause is responsible for the failure of tests made in winter are in progress in collaboration with Dr W. Hominick, Imperial College, London.

J. M. S. Forrest
M. S. Phillips
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The Commonwealth Potato Collection

Sowings were made for final PSTV tests and residual old seed was destroyed. Reserve seed from the Dutch-German collection at Braunschweig was received for safe-keeping.

The seed stocks, of lines which have been declared free of PSTV, are being increased. In September, seed of about 500 progenies was sown for final PSTV testing. These were of two different classes of material; that of which seed had been produced in 1972, during the first emergency programme for PSTV testing, but which had not, at that time, been unequivocally declared free of PSTV and other material which, while declared free of PSTV, required multiplication and of which the only available seed dated from before PSTV clearance and, therefore, requires re-testing. All residual seed, not from PSTV tested plants, was destroyed.

A batch of seed samples has been received for safe-keeping from the German-Dutch collection at Braunschweig in the Federal Republic of Germany. They are in moisture proof metal cans and are being stored in a deep-freeze, the seed having been dried to a suitable moisture content for prolonged low temperature storage before being sealed in the cans. The cans will not be opened in the UK but will be held available for return to Braunschweig in the event of the stocks there being lost. A batch of reserve samples from the CPC, for storage over silica gel at normal temperatures, was sent to Braunschweig in 1977 (*Ann. Rep. 1976-77*, 53-4).

About 30 samples have been distributed during the year, these going to seven institutes in the UK and one in the Federal Republic of Germany.

D. R. Glendinning

South American Cultivated Tetraploid Potatoes

Routine mass-selection of the existing Neo-Tuberosum population has been discontinued and seed is being stored for use when required. In a set of Tuberosum × Neo-Tuberosum progenies, the yields were determined almost entirely by the GCA's of the parents, the SCA contributions being negligible. The GCA's of the Neo-Tuberosum parents were positively correlated with their own yields. Information was obtained on the inheritance of disease resistances in the progenies of Neo-Tuberosum parents.

Routine mass-selection of the current Neo-Tuberosum population has been discontinued. It is doubtful whether much further inprovement could be achieved in this way, and it is known that the open-pollination relied upon involves much selfing and that this may result in random loss of alleles. The 1978 seed-production plot was a large and fully representative one, including material selected from seedlings grown from seed from both the 1975 and 1976 seed-production plots. Seed from this plot will be stored, samples being sown for special purposes such as the selection of clones, until declining

viability indicates a need for seed-renewal.

Further progress was made towards the establishment of an expanded 'Mark II' Neo-Tuberosum population (*Ann. Rep. 1977-78,* 56) which will require mass-selection in future.

Eighteen Tuberosum × Neo-Tuberosum progenies and the cultivars Pentland Crown and Craigs Royal were compared in a yield trial. This trial had four replications and plots of twelve plants each (two rows of six) with two foot (0·61m) spacing between plants. A progeny was normally represented by twelve genotypes taken from the F_1 generation and propagated vegetatively, but sometimes there were fewer genotypes and some then had two plants per replicate. Yields of tubers were recorded for each plant separately and plot yields were determined by averaging those of surviving plants, there having been a very few losses. The mean yield was 1936g per plant and the coefficient of variation was 10·7 per cent.

Of the eighteen progenies, thirteen involved six Neo-Tuberosum parents each of which had been crossed with at least two of three Tuberosum parents; the other five involved further Neo-Tuberosum parents each represented in a single cross. An approximate analysis of variance of the yields of the thirteen progenies can be made to obtain rough estimates of the general combining abilities of both the Tuberosum and Neo-Tuberosum parents (Table 14). There is no indication that specific combining ability is of any importance in this set of crosses.

TABLE 14

Yields (g. per plant) of Tuberosum × Neo-Tuberosum progenies compared with those of the Neo-Tuberosum parents.

Neo-Tuberosum parents	*Parental yields* †	*Tuberosum parents*			*Estimated g.c.a.*
		2895fg(6)	3681ad(1)	3683a(2)	
		progeny yields			
Gl.71/ 94	1403	1894	—	1349	−264
Gl.71/105	1016	—	1803	1494	−236
Gl.71/109	2500	2700	—	2159	+544
Gl.71/112	1464	1843	1946	—	−284
Gl.71/123	2067	—	2266	1616	+ 56
Gl.71/125	1527	2459	2415	1629	+185
Estimated g.c.a.		+196	+194	−390	

Analysis of variance of progeny yields

	d.f.	*Mean square*	*Variance ratio*
Between Neo-Tuberosum parents	5	323362	19·9**
Between Tuberosum parents	2	685449	42·1*
Interaction between parents	5	16278	n.s.
"Error" ††	57	42852	

Correlation of parental yields with estimated g.c.a. of the Neo-Tuberosum parents: $r = +0{\cdot}84$*

* $P<0{\cdot}05$ ** $P<0{\cdot}01$

† Parental and progeny yields are not directly comparable as they were determined in different years.

†† "Error" derived from the entries v. blocks interaction of the whole 20-entry v. 4-blocks trial.

Of twelve plants of each of these Neo-Tuberosum parents planted in 1973, from three to ten survived the severe roguing for virus infection required that year, and data from that harvest can be used to provide estimates of the yielding abilities of the parents (Table 14). Although these estimates are undoubtedly crude, they are significantly correlated with the estimates of the general combining abilities of the parents.

Pentland Crown and Craigs Royal had yields of 2165g and 1760g per plant respectively, and in comparison with these the yields of the experimental progenies were generally satisfactory.

A large replicated 'assessment' planting of Neo-Tuberosum clones and control varieties was made but analysis of the data is incomplete. Most of the clones were selected at Blythbank in 1976 and were derived from 23 parents, selected in 1971, of which fifteen had been crossed with various of the other eight. These same parents were used in the commercial breeding programme in 1974 giving rise, among others, to the eighteen progenies in the yield trial discussed above. Information on the disease reactions of the parents was used as a guide in choosing the submissions from the 1976 clones for tests by the Potato Pathology Department.

The results confirmed the presence of resistance to virus Y in derivatives of the parents Gl.71/96, /112, /119, /151, /172, /190 and probably /193. They supported previous evidence that the resistance in Gl.71/190 is of a comprehensive type, effective against viruses Y, VN, A and C, though some inconclusive test-results leave open a possibility that the clone may carry two or more different alleles, effective against various of these four related viruses. If a single comprehensively-effective allele is involved, the locus in Gl.71/190 is probably duplex for it because resistance appeared to be present in at least eight of the nine derivatives of the clone. (The expectations are that if the locus is simplex for the allele one-half of the outcrossed progeny will have resistance, as against five-sixths if the locus is duplex).

Sixteen of the twenty-three parental clones had resistance to virus X and in tests of 101 of the clones selected in 1976, which had one or both parents resistant, only two were shown to be susceptible though the results from many others were inconclusive.

A total of 107 clones were subjected to whole-plant blight resistance tests, there generally being good agreement between the scores given to the two plants tested of each clone. The parents had been assessed in leaflet tests in 1972 when four of them, Gl.71/101, /105, /151 and /175, had appeared most resistant. Of 45 clones obtained by crossing these four parents with various of the others the proportions receiving mean scores of seven or better, four to six and a half, or under four were eighteen per cent, 53 per cent and 29 per cent respectively while for the remaining 62 clones they were five per cent, 35 per cent and 60 per cent, the superiority of these four parents thus being confirmed.

Sixty-five clones were assessed, as three plants each, for scab resistance, at Archerfield, E. Lothian. When the 23 parents of the clones were assessed some years ago Gl.71/105 appeared the most resistant clone, and on the basis of the present tests it appeared the best parent. There was a significant rank correlation coefficient ($r = +0{\cdot}74$, $P<0{\cdot}05$) between the placings of the eight parents which had been crossed with the other fifteen and the previous placings of those eight clones themselves.

Preliminary tests for eelworm resistance were made on 43 clones, chosen to provide some representation of each of the 23 parents because nothing was known of parental resistances. The results suggested that some resistance may occur in Neo-Tuberosum, few of the clones being as heavily infected as the Pentland Crown controls and some having less than 40 per cent of the infection of the controls with both pathotypes A and E. Eight out of ten clones selected from progenies of Gl.71/96 crossed with various others showed evidence of some resistance to both pathotypes.

D. R. Glendinning

Studies of the potential of South American Diploids and Tuberosum Dihaploids for Potato Breeding

Inheritance of the ability to produce diploid pollen grains (diplandroids) does not appear to be governed by a single recessive gene as previously believed. Tetraploid progenies obtained by crossing diplandroid-producing Phureja diploids onto Tuberosum tetraploids appear relatively uniform and are high yielding.

Diploid clones selected in Cornwall, where blight is often severe, tend to be more blight-resistant than clones selected in Scotland.

Further data on the disease resistances of dihaploid clones have been obtained; some dihaploids are more resistant than their tetraploid parents. Tetraploids obtained by colchicine-treatment of dihaploids appear to retain the disease resistances of the dihaploids.

GENETICS AND BREEDING OF DIPLOID POTATOES (GROUP PHUREJA/STENOTOMUM)

The ability to produce diploid pollen grains (diplandroids) is important in the direct crossing of improved diploid potatoes, as male parents, with tetraploids of the Tuberosum group. Mok & Peloquin (*Heredity*, **35**, 293) have postulated that the "parallel spindle" abnormality, which leads to diplandroid formation in SPBS diploid stocks, is controlled by a single Mendelian recessive gene: *ps*. Last year (*Ann. Rep. 1977-78*, 57) a cross between two "carriers" for the parallel spindle factor gave ambiguous seg-

regations. Accordingly, during 1978 a series of ten test crosses were analysed in the hope of elucidating the mode of parallel spindle inheritance. Progeny from the previous cross which produced only normal (haploid) pollen were crossed with diplandroid producing testers. Segregations are shown in Table 15. In the crosses listed, the segregation ratios, due to a recessive gene *ps*,

TABLE 15

Results of crossing plants having entirely normal pollen with diplandroid-producing plants

		Number in progeny:	
Progeny No.	*Male tester*	*With Diplandroids*	*Without Diplandroids*
TC32	DB152(31)	11	3
TC33	DB152(31)	16	3
TC34	DB152(31)	12	1
TC35	13T48	12	5
TC36	13T48	10	9
TC37	13T48	3	4
TC38	13T48	14	5
TC39	13T48	8	11
TC41	13T48	11	9
TC42	13T48	14	5

would be expected to be either 1:1 or 0:1 (diplandroid:normal), and the observed frequencies of diplandroid producers greatly exceed these expectations. The difference between the ratios of diplandroid progeny produced by the two tester parents was subjected to a chi^2 test and is significant at the one per cent level. Such results cannot be explained on the basis of a single gene effect.

A representative sample of current Group Phureja diploids is grown each year on a site in West Cornwall (Rosewarne Experimental Horticulture Station) for assessment and selection under conditions of severe natural infection by potato late blight (*Phytophthora infestans*). Blight levels were particularly high during the 1977 season and tuber-blight was prevalent throughout the observation plots. At harvest time the three plants making up each clonal plot were dug and their tubers given scores ranging from zero (equal to no blight) to two (equal to strongly blighted); in this way total plot scores had values from zero to six. The planting contained eleven clones selected as seedlings at Rosewarne in 1974 and 1975, which could be compared with nineteen clones selected as seedlings at the Murrays in the same years. Both samples belonged, therefore, to the same generations of mass-selection. Mean plot scores for tuber-blight were as follows: Rosewarne seedlings, 2·95; Murray seedlings, 4·37. The use of a site with a high natural incidence of blight seems to be effective in identifying seedlings with better field-resistance in a population under mass-selection. In Scotland tuber-blight is only occasionally observed on diploid potatoes, in wetter seasons and the wetter parts of fields.

The larger numbers of selected progeny now entering the Murrays evaluation plots enable data to be obtained on which to base the choice of parent in tetraploid × diploid crosses. For example, in 1978, clones were available from crosses of Pentland Dell with two different diploids from the Phureja group, both diplandroid producers with high yields and reasonable tuber shapes. In the field each progeny was represented by a number of constituent clone plots and each clone plot contained five replicate plants (except where roguing of individual plants occasionally reduced the number). The provision of frequent check plots of a commercial control variety means that local fluctuations in yield due to soil conditions can be identified. The results for the Pentland Dell × diploid progenies are shown in Table 6.

TABLE 16

Mean yields and tuber weights of progenies from Pentland Dell × 13T8 and Pentland Dell × 13T48.

	Mean yield (g/plant)	*Mean Tuber Weight (g)*
Pentland Dell × 13T8	2342·9	200·3
Pentland Dell × 13T48	2311·9	172·2

The analysis of variance showed that there is no reason to prefer either diploid parent although significant differences existed between the clones within the two progenies for both yield and size. Similar comparisons were made between the diploids using Maris Piper as the tetraploid parent: again no differences in progeny yields and tuber sizes were detected. The possibility of differences due to the tetraploid parent must also be taken into account in inter-ploidy crosses. 13T8 was crossed as pollen parent with both Pentland Dell and the old cultivar Golden Wonder, which is sexually fertile and of high cooking quality, but of lower yield and size. The results are shown in Table 17.

TABLE 17

Mean yields and tuber weights of progenies from Pentland Dell × 13T8 and Golden Wonder × 13T8.

	Mean yield (g/plant)	*Mean Tuber Weight (g)*
Pentland Dell × 13T8	2068·7	160·2
Golden Wonder × 13T8	1373·4	99·6

The data show that the progeny of Pentland Dell had very significantly higher yields than those of Golden Wonder. In this instance differences between clones within progenies fell just short of significance. There was also an advantage in tuber size in using Pentland Dell rather than Golden Wonder.

A comparison of Arran Consul with Pentland Dell, using the diploid 13T48 as pollen parent, revealed no significant progeny differences in yield and tuber size. It is intended in future work to extend the range of diploid and tetraploid parents so as to identify particularly high yielding combinations.

The next stage in the transfer of improved germ-plasm from the diploid to tetraploid level requires crosses to be made between tetraploid F_1 hybrids and selected diploids which are themselves hybrid, combining Tuberosum dihaploids with improved Phureja diploids. During 1978 suitable elite hybrids at the diploid level have been screened for their ability to produce diplandroids, and three hybrids have been used in exploratory crosses with tetraploids.

C. P. Carroll

PATHOGEN RESISTANCE OF DIHAPLOIDS

The identification of new dihaploids with high levels of quantitative resistance to pathogens continued. Altogether 32 dihaploids have shown high resistance to foliage-blight (*Phytophthora infestans*) in whole plant tests, another six have high tuber-blight resistance and four have good resistance to eelworm (*Globodera pallida*) UK pathotype E.

Four Pentland Crown dihaploids have been widely used in crosses over the years with other dihaploids and Group Phureja clones. They have given what are, for dihaploids, high yields and have tubers of a fair size and shape. As a consequence of their age and widespread use these clones have been subjected to tests for pathogen resistance more than most and Table 18 presents a summary of results, each resistance being expressed as a percentage of that of Pentland Crown. So far, two have shown a degree of resistance significantly higher ($P<0.05$) than that of their parent (PDH7) for foliage-blight (from detached-leaflet tests only) and PDH52 for tuber-blight resistance. PDH40

TABLE 18

Pathogen resistance of four Pentland Crown dihaploids as a percentage of that of Pentland Crown.

	Dihaploid			
Pathogen	*PDH7*	*PDH40*	*PDH52*	*PDH55*
Foliage Blight	145†	161	138	138
Tuber Blight	46	20	123†	117
Leaf Roll	63	201	126	109
Gangrene	—	49	13	17
Eelworm pathotype Pa3	133	58	108	95

† Resistance of dihaploid is significantly higher than that of Pentland Crown ($P<0.05$)

however, has proved useful for producing largely tetraploid progenies from dihaploid × tetraploid crosses. It produces unreduced female gametes, though whether by first or second meiotic division restitution is as yet unresolved. Two such progenies have produced plants which grew vig-

orously in pots and gave a good crop of fair-sized tubers. Of seven tetraploids obtained from a cross of PDH40 with a *vernei*-derived tetraploid, three showed high resistance to foliage-blight in whole plant tests. Data on the blight resistance of the ex-*vernei* clone are incomplete so that it is not possible at present to decide what proportion of the hybrids' resistance is likely to derive from each parent.

Tetraploids, produced by colchicine treatment, of another highly foliage-blight resistant dihaploid gave resistance scores similar to that of the original dihaploid. Some doubled dihaploids have set seed in crosses with other tetraploids and may in some cases be more fertile than the original dihaploid clones.

Deep-frozen, desiccated pollen has been used to extend the crossing season, especially for dihaploid-induction crosses; there appear to be few ill-effects of this method of storage on potato pollen and pollinations may actually produce more uniform results than those made with fresh pollen, though this is more likely to be due to the stored samples containing mixtures of pollen from many different flowers than to the method of storage. Pollen quality can vary from flower to flower, and when fresh pollen is used it may be taken from only a few flowers.

M. J. De, Maine

AGRONOMY DIVISION

Field Trials Unit

Routine testing of advanced breeding lines, from the station's Forage Division, continued at the regional centres in Scotland and Northern England. The cereal, kale and swede trials were late drilled because of the very inclement weather during March and early April. Drilling took place ten to twelve days later than average and cereal harvesting was correspondingly later. The 1978-79 winter wheats were drilled in late October; considerable expansion has taken place in the appraisal of advanced lines for the Plant Breeding Institute, Cambridge. This material will be selected for suitability for South-East Scotland.

Cereal drilling took place during early mid-April. Magnesium deficiency was noted at the commencement of tillering and magnesium sulphate was applied with the herbicide. Mildew and yellow rust were present at moderately high levels, some *Rhynchosporium* and brown rust were noted but both failed to establish. Frit fly (*Oscinella frit*) was a particular problem in the spring oat trials, reducing yield and necessitating the application of desiccant before harvest. Barley trials and the variety demonstration and multiplication plots were harvested in mid September. The Spring oats were cut in late September. Bird damage and ear loss at harvest were of minor importance but there was some brackling in the barleys.

The extremely mixed weather continued into May, delaying drilling of the swede and kale trials beyond the optimum dates. Low infestations of insect pests were present throughout the season. Three applications of insecticide was found necessary to control flea beetle (*Phyllotreta* spp.) because of the very prolonged attack. Mildew (*Erysiphe cruciferarum*) was present in the swedes, reaching quite high levels in the very susceptible cultivar Doon Major.

Two swede and two cereal selections, all un-named, have been submitted to official trials for Plant Variety Rights following the Unit's 1978 trials. Descriptions and reports of their performance appear in the reports of the appropriate departments in this Annual Report.

The Unit was provided with an excellent small tool and machine store at Pentlandfield. Valuable field equipment previously inadequately housed can now be properly stored. Storage of equipment was previously a major problem. A new Land Rover was obtained for visiting and servicing trials, allowing the Unit greater flexibility in planning its work programme in the field. No new trials field machinery was obtained this year.

I. M. Chapman
A. Young

Murrays Farm Unit

The year was marked by a wet, cold spring and a wet July and August.

The renewal of the farm drainage system, which was begun in February 1977 was completed between October 1978 and January 1979 by the drainage of the following fields: Cottage, Hollow, Folly, Sunnyside and Reserve A. Minor problems have occurred where old drains had not been cut into the new system but these appear to have been resolved. With the co-operation of Prestonhall Estate, the outlet from the ditch in Cottage field, which carries most of the water from the farm, was cleaned out, through Prestonhall ground, to the Murrays burn.

The poor spring delayed barley sowing in 1978. A start was made with the cereal trial plots in Sunnyside on April 9th. The sowing of 57 ha commercial barley started on April 19th and was completed on May 14th. Two hectares of barley disease trials were sown in each of Crow and Wee Murrays fields. The commercial barley variety was Golden Promise, treated with a mildewicide seed dressing. Fertiliser (22-11-11) was applied to the seed bed at the rate of 376 kg ha^{-1}. After sowing, a prolonged dry spell restricted growth and the crop did not fully recover. Yields varied from 2·1 t ha^{-1} to 3·9 t ha^{-1} and averaged 3·3 t ha^{-1}.

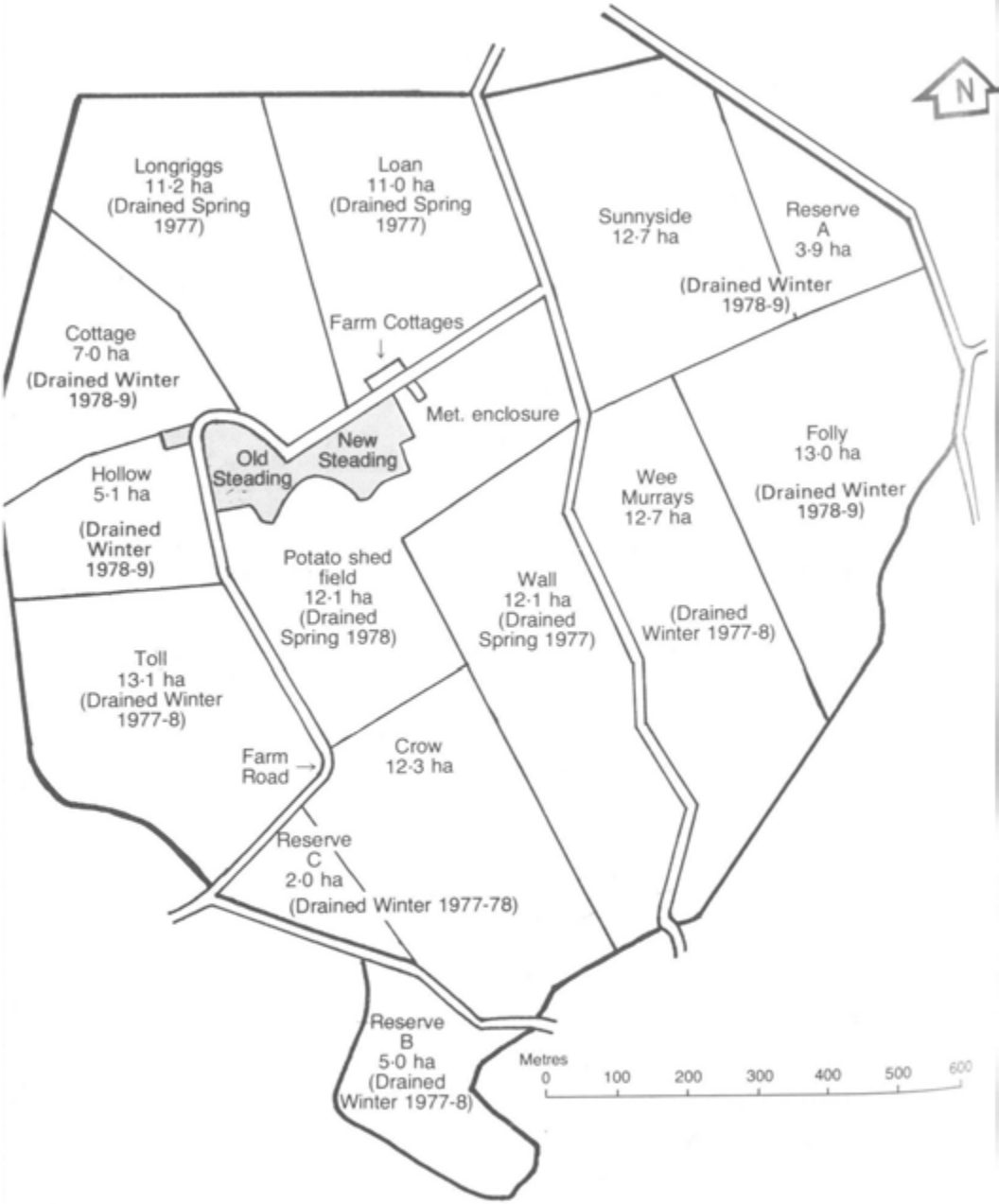
The Kinsman winter wheat, which had been sown in 1977 in Loan, was top-dressed with 376 kg ha^{-1} (22-11-11) in April and 125 kg ha^{-1} 'Nitram' (34·5%N) in May and yielded 6·04 t ha^{-1}. Winter wheat *cv* Score in Wall was top-dressed with 376 kg ha^{-1} (22-11-11) in April and, at harvest, yielded 4·6 t ha^{-1}. Score lodged badly but Kinsman stood well.

Potato planting started with a trial of early varieties on May 9th and the main planting was made between the 12th and 25th of May. Before planting, 1256 kg ha^{-1} potato fertiliser (15-15-19) and E.P.T.C. herbicide ('Eptam') were incorporated in the soil and phorate granular aphicide ('Thimet') placed in the drills before covering. Metribuzin herbicide ('Sencorex') was sprayed at emergence. Spraying, at two week intervals, with alternate systemic aphicides (demeton-S-methyl and demephion) started in mid-June and continued until the end of August. From early July, pirimicarb was sprayed in the intervening weeks. From the end of July a fortnightly blight spray (maneb plus fentin hydroxide, 'Du-ter 50') was added. The spraying of pirimicarb was continued until mid-September.

The early potato trial was harvested at the end of July and main-crop harvesting was carried out between mid-September and the end of October. Yields were good. After harvest part of the field was harrowed and hand picked to remove ground keeping tubers but bad weather prevented the completion of the harrowing. The field has since been chisel ploughed in an attempt to increase the effect of frost in killing any remaining ground-keepers.

The grass in Hollow and Cottage was top dressed with fertiliser at 400 kg ha^{-1} early in March and cut for hay in mid-June. There was heavy rain

Map of the Murrays showing field areas and progress of drainage operations.



halfway through hay-making and, while the crop in Hollow was baled dry although slightly green, that in Cottage was badly weathered before it could be baled. Yield was 5·65 t ha^{-1} and the quality reasonable for the season. The aftermath was sprayed with glyphosate ('Round-up') to control weeds before draining.

Potato Shed field was left fallow, it was cultivated in mid-May and sprayed with glyphosate in mid July to kill ground keeping potatoes and weeds. The field was ploughed at the end of August, after the application of 125 kg ha^{-1} muriate of potash (50%). A strip of amenity grass was sown, along the side of the main approach road to the farm, immediately after ploughing. 'Mardler' winter wheat was drilled in the West side in mid-October following a seed bed application of 376 kg ha^{-1} fertiliser (8-20-16). The east side was sown with trials of winter wheat and winter barley at the same time and with the same fertiliser treatment.

Wall field was ploughed in October and 'Mardler' wheat drilled in the north half, 'Score' wheat was drilled in the remainder. After drilling a top-dressing of 250 kg ha^{-1} fertiliser (15-15-19) was applied. The winter wheat brairded well, though the 'Score' is not growing as strongly as the 'Mardler'.

Hollow and Reserve C were ploughed in the third week of October and beans (Throw's M.S.) were drilled at the end of October. Fertiliser (0-21-21) at the rate of 500 kg ha^{-1} was applied in the seed-bed. Before the onset of the cold weather the beans were growing well.

The fields sown with wheat and beans have a three metre margin not sown which will be cultivated and sprayed to control weeds.

During the autumn the back road through the farm has been regraded and levelled off with blaes. A new farm road along the south fence of Sunnyside and Reserve A was constructed and has greatly improved access to these fields and to Folly. Another road has been made along the north fence of Crow to provide access to the west side of Wall field.

Work has started on a new loading bank outside the implement shed and it should be completed soon. This will avoid the necessity for travelling to a neighbouring farm to load and unload implements from lorries.

It is a pleasure to record the awarding of Craftsman Certificates to two of our tractor drivers, David Ritchie and Gordon Tait, at a ceremony at the end of January. They completed the three year course, organised by the Agricultural Training Board, in September. The course involved day release and block release training at Oatridge Agricultural College followed by written and practical examinations as well as proficiency tests organised by the Young Farmers' Centre. In addition David Ritchie was nominated from this area as a candidate for the Craftsman of the Year Award and Scholarship.

G. R. White

Meteorological Summary. The Murrays 1978.

TABLE 19

Month	Mean temperature °C Max.	Min.	Mean soil temperature °C 5 cm.	10 cm.	Number of days temperature < 0·0°C Air	Grass	Total rainfall mm.	Number of wet days >1·0 mm.
January	4·2	−0·5	0·7	1·2	16	19	60·0	11
February	2·7	−3·5	0·7	0·9	16	20	48·7	12
March	8·2	2·6	4·5	3·9	3	10	51·9	18
April	8·0	2·2	6·4	5·4	6	12	39·7	8
May	15·0	6·2	12·2	10·5	0	6	23·5	7
June	16·5	8·2	14·6	13·8	0	1	31·9	6
July	16·5	9·4	14·4	13·5	0	0	64·3	9
August	17·0	10·1	14·4	13·7	0	0	95·2	17
September	15·4	9·6	12·2	11·5	0	0	52·1	12
October	13·5	8·0	9·6	9·5	0	1	18·1	5
November	10·4	4·4	5·9	6·3	4	6	47·5	9
December	4·7	0·7	1·9	2·4	11	20	119·9	17
Annual total (364 days)					56	95	652·8	131
Annual mean	11·1	4·8	8·2	7·8				

Strategic Pathology Unit

Mechanisms of Field Resistance to Potato Blight and Variability of the Pathogen

The results of tests of tubers for susceptibility to blight were affected by the time of lifting the tubers and by the varieties involved. Conflicting evidence on the effect of date of inoculation was obtained in two series of tests and further investigation is required.

Genetic variation in progenies tested was attributable to general combining ability. Scores for the size and frequency of lesions on the leaves, petioles and stems and the overall grading of the plants were highly correlated.

A study of the possibility of adaptation of Phytophthora infestans *to highly resistant clones was started.*

Races 2, 3, 4 and 3, 4 of P.infestans *were isolated from blighted specimens from various locations in the east of Scotland.*

The recording of the incidence of blight on tubers, in studies initiated in 1977 (*Ann. Rep. 1977-78,* 67), was completed. Analysis of the results indicated significant differences in the reactions of the nine cultivars examined. In the tests, which were made at weekly intervals, during August, the tubers lifted before the middle of the month were significantly more susceptible than those lifted later. For all four lifting dates more blight developed in the tubers inoculated one, two and three weeks later. There was some evidence for interaction between variety and both lifting date and date of inoculation.

In 1978, tests of tubers lifted on the eighth of September, showed significant differences in the susceptibility of the four varieties used following inoculation on the day of lifting and one day or three days after lifting. However, in contrast with the tests in 1977, no effect of inoculation date or of interaction between variety and inoculation date was evident. The tests carried out in 1977 were made earlier in the year than those of 1978 and they involved a different time scale. Further studies are under way to examine possible reasons for the differences observed in the two seasons' tests.

Analysis of the results of tests of progenies of parents crossed in a multiple mating scheme (*Ann. Rep. 1977-78,* 68) were completed. In addition to an overall score, the size and frequency of the lesions which developed on the leaves, petioles and stems were used as criteria in assessment. All the statistically significant genetic variation was attributable to differences in general combining ability and the seven variates were highly correlated with each other.

A high level of field resistance was noted in several advanced selections derived from Pentland Ivory and Clone 3683a(2) (both well established as parents conferring resistance to blight) and five derivatives of *Solanum vernei*. A study of the possibility of adaptation of the fungus, with consequent reduction in level of resistance, was initiated with these clones and others with a similar level of resistance. *Phytophthora infestans* has been isolated from these clones and isolates maintained for future studies.

Multiplication of the series of differential hosts for races of *P.infestans* continued. In addition, progenies were screened to identify clones with R genes for further testing to establish alternatives for certain of the differentials in which the R gene reaction is considerably masked by a high degree of field resistance.

Specimens of *P.infestans* from various locations in East Scotland were predominantly of race 3 but race 4 (usually regarded as the common race) race 2 and race 3, 4 were also identified. Isolates of these races have been maintained.

J. F. Malcolmson

Statistics and Computing Service

The work of the section was considerably curtailed during the first half of the year because there was no scientific officer in post. Since the appointment of a Higher Scientific Officer, who joined the staff on 1st September 1978, the level of service offered to the institute's research staff has increased considerably. A full card punching and verifying service was maintained throughout the year.

Extensive use has been made of the EDEX package, developed at ARCUS, in Edinburgh, for the analysis of designed experiments and the CVT pack-

age, also developed at ARCUS is being increasingly used for the design and analysis of large experiments especially those using generalized lattice designs.

Three thousand and thirty-five jobs were run this year using the ERCC services and 71 per cent of these were run via the Edinburgh Multiple Access System.

The capacity of the institute's own computer, a Wang 2000 system, was considerably increased by the replacement of the original 4K memory by two 8K units. Two diskette drive units were also purchased, enabling quite large data sets to be stored on flexible disks and also the editing of files by copying from disk to disk. The section is gradually transferring straightforward data processing jobs to the Wang 2000. The Chemistry Department has made extensive use of the new facilities on this machine.

J. W. McNicol

SERVICE UNITS

Chemistry Laboratory

The work of the Chemistry Laboratory continues to be mainly concerned with routine analyses of quality factors important in plant breeding. In the autumn, the responsibility for malting quality assessment was transferred from Cereals to the Chemistry Department. Miss Frances Bruce, who has been in charge of this work, also transferred to Chemistry, and retained her former responsibilities. In addition Chemistry took charge of the malting quality laboratory.

A decision was taken, late in the year, to change our method of estimating digestibility. The majority of samples for this analysis will now be digested by a modified pepsin-cellulase method. Professor J. S. Hall, of the West of Scotland College of Agriculture, agreed that 200 samples (about ten per cent of our normal annual work-load) would be analysed by their Chemistry laboratory each spring using a rumen liquor method (our *in vitro* test was based on the WSCA method). This arrangement removes the need for the Chemistry Department to maintain sheep all year to obtain a three month's supply of rumen liquor. Two fistulated sheep were returned to HRFO. Our thanks are due to HFRO for their helpful co-operation over the past six years.

During the year, work continued on the development of the new milling energy apparatus, in collaboration with Calan Electronics Ltd. It was established that measurements of milling energy can be made about twice as rapidly and are more repeatable (preliminary results indicate a gain in repeatability from 0·83 to about 0·93) using this new apparatus, called a "Comparamill", than on the original apparatus. Milling energy values, estimated using the "Comparamill", had a high correlation ($r = -0{\cdot}76$, $P<0{\cdot}01$) with hot water extracts of micromalted samples of current varieties. Progress was also made in increasing the uses of our infra-red analyser, the "InfraAlyzer". As in 1977, the InfraAlyzer was used routinely for the prediction of nitrogen, soluble beta-glucan and moisture content of barley. In addition, this year, the InfraAlyzer was successfully calibrated to permit accurate estimation of the nitrogen content of brassicas, hill grasses and field beans; the latter two analyses were part of collaborative research work with HFRO and PBI, respectively.

The increase in automation of our routine nitrogen analyses allowed more time for the estimation of toxic factors in plant material. An electrophoretic method for determining S-methyl cysteine sulphoxide (SMCO), a haemolytic factor in kale, was used to screen breeding material for SMCO content. A total of 760 samples of various brassica genotypes were analysed for SMCO during the winter. These data are currently being analysed and preliminary

evidence indicates that the test may not be very accurate but is capable of distinguishing samples with high or low SMCO content over a range of 0·75 per cent to 1·5 per cent SMCO. An automated procedure was used to estimate thiocyanate content of the same material.

Our routine work this year included digestibility estimations (890 brassica samples and 64 grass samples), Kjeldahl nitrogen determinations (536 and 768 samples of barley and brassicas, repectively), the estimation of soluble nitrogen content (500 barley wort samples), the measurement of diastatic power (2454 barley samples) and alpha amylase content (394 barley samples), and S-methyl cysteine sulphoxide and thiocyanate content (760 estimations on brassica material).

In the period from August to December a total of 600 barley samples were assessed for malting quality by Miss Frances Bruce.

In the autumn a meeting of representatives of Chemistry Departments of WPBS, SPBS, PBI and NIAB was held at the PBI, Cambridge. Apart from useful exchanges of information regarding methods, it was also agreed that some samples should be exchanged between stations to be analysed for each of the main quality factors. It is hoped that such co-operation will increase confidence in results and provide a rapid means of exchanging ideas and details of new methods.

M. J. Allison
R. Borzucki
I. A. Cowe
R. McHale

Cytology Laboratory

The work of the Cytology Laboratory is mainly concerned with routine screening of plant breeding material for chromosome number and with the examination of pollen. This year there has been collaboration on research projects with the Brassica and Strategic Potato-Breeding departments.

Routine work for the Brassica department included pollen size measurements to identify tetraploids in colchicine-treated kale (*Brassica oleracea*) plants, and mitotic and meiotic counts of advanced hybrid material from *B.campestris* × *B.napus* and *B.oleracea* × *B.napus* crosses. Extensive meiotic analyses were made of semi-artificial *B.napus* plants with 38 chromosomes, a sample of the selfed progeny of three plants (2n = 36 or 37) obtained by crossing an allotriploid hybrid (acc, 2n = 38) with *B.napus* (*Ann. Rep. 1977-78,* 70). None of the 25 plants studied had a completely regular meiosis; two had only bivalents and univalents at metaphase I while the mean multivalent frequency per cell of the remaining plants varied from 0·13 to 1·20. At metaphase II, chromosomal segregations of 20:18 and 21:17 were found as well as the expected 19:19. These results, added to those reported previously (*Ann. Rep. 1977-78,* 70), confirm the difficulty of obtaining stable breeding lines from aneuploid plants.

The monosomic addition lines (2n = 21) of *B.campestris* with an extra *B.oleracea* chromosome (*Ann. Rep. 1977-78,* 70) were selfed this year to obtain plants with a pair of additional *B.oleracea* chromosomes. Eight monosomic parent plants were analysed at meiosis and of 468 metaphase I cells, 436 had the expected configuration of ten bivalents and one univalent. Twenty-eight of the remaining cells contained a trivalent. Fewer metaphase II cells were examined but eighteen per cent had irregular segregations with lagging chromosomes excluded from the spindle. These plants were bud selfed and chromosome counts made of the progeny. Three plants with 22 chromosomes, i.e. disomic addition lines with a pair of identical *B.oleracea* chromosomes, were identified; each was derived from a different 21 chromosome parent. The proportions of 22 and 21 chromosome plants, one per cent and twenty per cent respectively, were much lower than the expected frequencies of 25 per cent and 50 per cent. The observed irregularities of meiosis may help to explain the lack of 21 and 22 chromosome plants in the progenies, but reduced viability of eleven chromosome gametes may have a greater effect.

Attempts were made to identify the extra *B.oleracea* chromosome by size but these were unsuccessful. The karyotyping of plant chromosomes has been facilitated by the development of methods of producing specific bands on individual chromosomes (Schweizer, *Chromosoma,* **40**, 307-20), and progress has been made in applying these methods to *Brassica* chromosomes.

Routine pollen fertility estimates were made of 40 potato clones from the commercial breeding programme and 600 clones from the diploid/dihaploid programme. Plants from the dihaploid and tetraploid hybrid production programmes were examined cytologically and 68 new dihaploids and 230 new tetraploids were identified. The frequency of aneuploidy in material derived from 1977 pollinations is similar to that found last year.

The inheritance, in potatoes, of the ability to produce diploid pollen grains (diplandroids) has been studied this year. Crosses were made in 1977 between plants all of whose pollen was 'normal' (i.e. haploid) and diplandroid-producing testers (*Ann. Rep. 1977-78,* 59) and 166 of the progeny were scored for pollen stainability and presence of diplandroids. The results are discussed elsewhere in this report (p 75).

Colchicine-treated plants, obtained last year, from five dihaploid potato clones were examined and completely tetraploid individuals were obtained from one clone only. Plants examined in 1976 and 1977 and found to be tetraploid in the outer and innermost layers, were clonally propagated. Tubers from these plants were screened this year and eighteen of the 26 clones produced fully tetraploid plants.

Judy Fantes

Photography and Illustration

There has been, during the past year, a considerable increase in demand for

both photographic services and for assistance with graphic work. The former was met largely by the expansion of facilities for the production of colour prints from both negatives and from transparencies, the latter being accomplished by the 'Cibachrome' process. This technique has been used mainly for the production of display material but has also proved a useful addition to the service generally.

A new display system was acquired and has permitted considerable improvements both in the appearance and flexibility of pictorial demonstrations.

A room has been set aside in which to mount a semi-permanent display, illustrating the activities of the institute; the equipment of this room is now complete and a committee has been formed to choose material for display.

G. Cruickshank

Library

During 1978, a continuing steady increase in the use of library facilities has been evident. An improved financial situation has enabled the backlog of binding to be completed and has allowed for a more generous book acquisition policy. One hundred and twenty nine books were bought as against 55 the previous year and many gaps in the existing stock have been filled.

TABLE 20

Library Statistics – 1978

1977				*1978*
222	Library Loans			402
	Interlibrary Loans			
79	Borrowed — British Library	147		
67	— Other Libraries	64		211
11	Items lent			12
35	Requests for Station Publications			76
	Literature Searches			
	Computer	29		
23	Manual	22		51
5	Other Enquiries			26
55	Book Acquisitions			129
4	New Journal Subscriptions			5
2	Cancelled Journal Subscriptions			5
1	Courses/Meetings Attended			5
	Translations			1

Following the journal use survey carried out last year, a total of five seldom used titles were cancelled which made it possible to take out subscriptions to five new titles — *Physiological Plant Pathology, Cereal Chemistry, Biochemical Genetics, Annual Review of Phytopathology* and the *Life Sciences* section of *Current Contents*.

In addition to the monthly accessions lists, regular current awareness lists of relevant journal literature and items of interest are now being circulated. These have resulted in a marked increase in the number of items requested on loan. Internal loans have almost doubled over the year and external loans have increased by 45%.

Fifty-one literature searches were undertaken on a variety of subjects ranging from techniques of infra-red reflectance to host finding behaviour in nematodes. Twenty-nine of these were run by computer using the Lockheed DIALOG service which has been available to the Station since May. User response to these computer searches has been mostly favourable and it is hoped to make more use of the different data bases available in the future.

Barbara Hay

Workshop

Attention to "Health and Safety at Work" is routine and inspections are made regularly. In addition to making machinery and electrical installations safe, a number of improvements affecting staff health have been carried out, e.g. asbestos roof and boiler insulation, a definite health hazard, was removed by specialist contractors and replaced by other insulating materials; the insulation against heat loss, of the workshop roofs, which are clad with asbestos sheet, has started and the joiner's workshop can now be easily maintained at a comfortable temperature; a cyclone to remove dust from a grain dryer at the Murrays was installed and the making and installation of a dust and fume extractor for the workshops is nearing completion; the level of lighting in the original building has been raised by installing fluorescent lighting.

The routine servicing and maintenance of vehicles and other motorised equipment, implements, buildings and glasshouses, together with the modification and construction of new equipment such as benches and insect-proof porches for glasshouses and the construction of three constant environment chambers (in collaboration with a refrigeration engineer) has taken up much workshop time. The maintenance of the old wood-framed glasshouses continued, by the use of hot water under a high pressure to clean the woodwork followed by treatment with a wood preservative. The glasshouses were then reglazed using a proprietary glazing tape.

The roofs of aluminium glasshouses, in which mastic had been used to seal the glass to the metal frame, developed a heavy growth of moss on the mastic; this was removed but regrowth was rapid and after ten years the glass has been forced from the metal causing numerous leaks. The roofs of two glasshouses have been reglazed by a contractor and the mastic sealant replaced by plastic which it is hoped will assist in keeping glasshouses free from moss.

A central store, constructed and fitted by the workshops, is now in use with a storeman in charge.

A. E. Hamilton
D. W. Speed

BREEDING FOR MALTING QUALITY AT THE SCOTTISH PLANT BREEDING STATION

M. J. ALLISON, R. P. ELLIS, A. M. HAYTER and J. S. SWANSTON

Introduction

In the United Kingdom the barley crop is put to two main uses, the production of malt (about twenty per cent of the total crop), and feed (about 60 per cent); of the remaining twenty per cent, some is exported, and there are also specialised requirements e.g. pearled barley. Different kinds of malt are required depending on the intended product. For example, a malt for beer manufacture and malt whisky should have a certain proportion of the endosperm starch converted to simple sugars, but may only have moderately active levels of starch-degrading enzymes (collectively called diastase). In contrast, malts used to make grain whisky, should have high diastatic activity to convert the malt and adjunct (usually flaked maize) starch to fermentable sugars (Pyke, 1965).

The need for malts with specific properties for the manufacture of beer and whisky can be demonstrated by comparing the mash tun components (mashing is an early step in beer and whisky manufacture) in the different processes. Mashes for the manufacture of Scotch malt whisky and most beers consist solely of barley malt although maize adjunct, up to 30 per cent of the total, may be used for certain beers and lagers. For all of these mashes it is necessary to use barley that modifies readily with fast endosperm breakdown during malting. In addition it is usually necessary for the nitrogen content (used as a measure of protein content) of the barley to be between 1·4 per cent and 1·7 per cent. Above this range the extract decreases as proteins occupy space in the cell normally available for starch deposition (Bishop, 1948). When nitrogen content is below 1·4 per cent the level of amino acids in malts is insufficient to maintain adequate yeast growth during fermentation (Enari, 1974). High α-amylase activity is also needed as this enzyme initiates the attack on granular starch (Dunn, 1974).

In grain whisky manufacture barley malt comprises about twenty per cent of the mash, the other 80 per cent is adjunct. There is a need, therefore, for malts with high starch degrading activity (diastatic power) to convert barley and adjunct starch to fermentable sugars. Not only is the starch substrate of the barley less important in this process, there is also a change in emphasis to β-amylase, rather than α-amylase, activity as the starch adjunct is added in solubilised form to the mash.

These differences in the industrial processes led to the formulation of two distinct breeding objectives at this station. In both cases agronomically

well-adapted barleys were required, with high diastase for grain whisky manufacture and with good amylase and endosperm properties for beer and malt whisky manufacture. The biochemical aspects of both of these objectives depend upon changes occuring during the development of the barley grain and its subsequent germination. As an introduction therefore, to work on breeding for these objectives at this station, the relevant features of barley grain structure and biochemistry will be described briefly. This is followed by reviews of our work on high diastase and malting quality breeding together with accounts of related research work.

Structure and Biochemistry of the Resting Grain

The barley kernel is an indehiscent fruit, or caryopsis, enclosed by a husk comprising the palea and the lemma. With the exception of some naked varieties and some unusual varieties e.g. Glacier, the husk strongly adheres to the kernel. The husk has several layers of cells, with thickened cell walls which are lignified and consist of cellulose, β-glucans and pentosans. The latter differ from endosperm pentosans in having glucuronic acid residues (Aspinall and Ferrier, 1957). Both the β-glucans and pentosans are families of molecules differing in molecular weight and, in certain cases, chemical composition. Low molecular weight forms tend to be soluble in water and are classified as water-soluble gums, whereas the water-insoluble high molecular weight polymers are classified as hemicelluloses. The ratio of pentosan to β-glucan in these outer layers is approximately 4:1. Husk cells have no starch.

The next layer inside the husk, the pericarp is also a starch-free dead tissue. During grain development, however, the pericarp and testa, formed from the ovary wall and integument layers respectively, contain starch and are well developed, metabolically-active tissues, particularly in the first twenty five days after anthesis (Allison *et al*, 1974). The testa-pericarp produces α-amylases (which have about 1/150th the activity of that observed in malts) and these reach a peak of activity between seventeen and nineteen days after anthesis (Riggs and Gothard, 1976; Allison *et al*, 1974). It has been suggested (Allison *et al*, 1974) that short glucose chains, released from testa-pericarp starch by α-amylase action, may serve as primers for the extensive starch synthesis that occurs in the endosperm during grain development.

The embryo also contains little or no starch, although a few starch grains are present in the scutellar epithelial cells (Harris, 1962), but it is rich in lipids (fourteen to seventeen per cent of the dry weight), (Parsons and Prince, 1974), sucrose (fourteen to fifteen per cent), (Pollock, 1962), raffinose (five to ten per cent), (Pollock, 1962; Briggs, 1978), and a series of higher fructosans (Briggs, 1978). A small amount of reducing sugars, including maltose is also present (MacLeod, 1960). Embryo tissues are nitrogen-rich with a crude protein content (mainly lysine-rich proteins) of about 34 per cent (Brown, 1909). Cell walls in the embryo contain some cellulose and pectin in addition

to β-glucans and pentosans.

From the point of view of malting, the aleurone layer is important. Aleurone cells are thick-walled with a dense cytoplasm rich in cell organelles but with no starch. These cells are sensitive to the hormone, gibberellic acid (GA), and in response to GA undergo physiological and biochemical changes culminating in the synthesis and secretion of hydrolases which are important in starch degradation and malting. The aleurone layer also contains most of the lipid of de-embryonated grains, stored in the spheroplasts. Other aleurone organelles include densely-staining granules containing phytic acids and proteins (Jacobsen *et al,* 1971). The cell walls are relatively thick with a high content of the pentosan, arabinoxylan (85 per cent), plus cellulose (eight per cent) and proteins (six per cent).

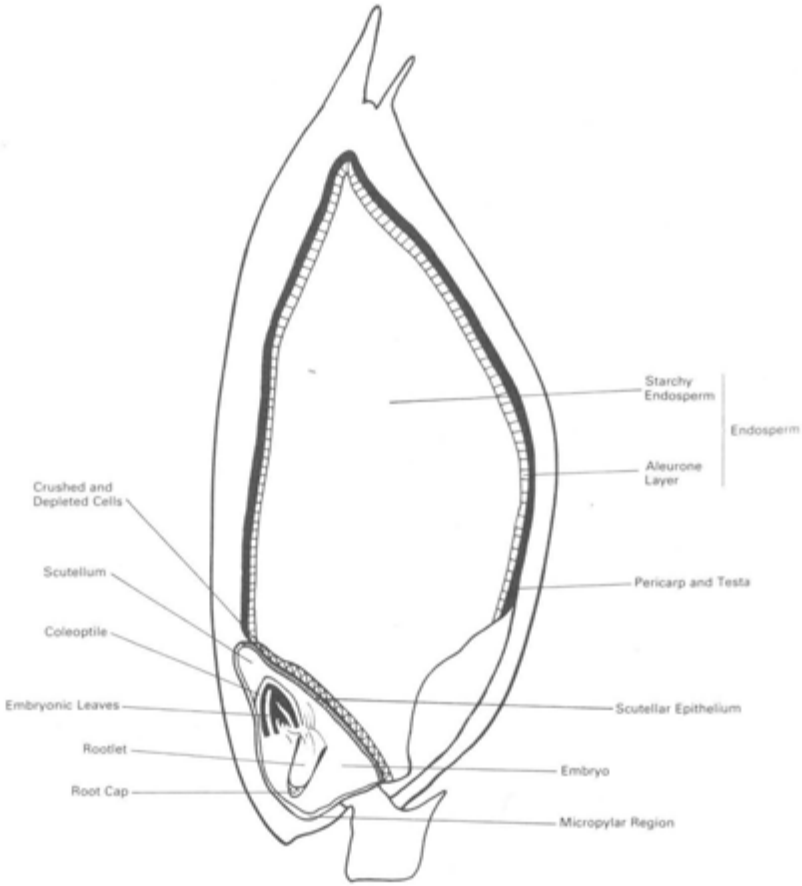


Figure 1. Diagrammatic representation of a barley grain.

Between the aleurone and the starchy endosperm is the subaleurone layer of cells. This is richer in protein (Levy, 1936) and lower in starch than the adjoining starchy endosperm (Vine, 1913). Associated with the proteins in this zone is the hydrolytic enzyme, β-amylase (Tronier and Ory, 1970). Pearling experiments (in which the outer layers of the grain are removed successively) have demonstrated (Engel, 1947) that nearly all of the β-amylase in barley is located in this zone. β-Amylase activity is first observed at about fourteen days after anthesis (Duffus and Rosie, 1973) and survives, throughout development, to grain maturity, eventually to play a part in modification of the starchy endosperm during germination. During grain development the enzyme undergoes increases in molecular weight and changes in electrophoretic properties, either by forming multimers or by combining with other proteins (Laberge *et al,* 1971) at some stage in the transition from immature grain to malt. There are at least two forms of β-amylase (Sallans and Anderson, 1938), a water-soluble active form ("free" β-amylase) and a bound inactive form ("latent" β-amylase) which is converted to the free active form by reducing agents which have thiol groups or by the appropriate enzymes (Shinke and Mugibayashi, 1971).

Approximately 64 per cent of the dry weight of a well filled two-row barley grain is starch and this is the main constituent of the starchy endosperm. The starchy endosperm also contains nitrogen both in the form of a proteinaceous matrix in which the starch granules are embedded and as protein bodies containing storage proteins, particularly hordein (alcohol-soluble protein). It has also been suggested (Badenhuizen, 1973) that enzymes such as starch synthetase, active in starch synthesis, become enclosed within the starch granules during granule formation. In contrast to the husk layers, endosperm cell walls have no pectin or cellulose. There is a high ratio (approximately 4:1) of β-glucan to pentosan (Fincher, 1975), which is the reverse of that observed in the husk layers or in wheat endosperm cells. As in the husk, both of these polyglucans are in the form of gums and hemicellulose (MacLeod, 1960). Between four to seven weeks after anthesis, polymer synthesis in the developing grain slows down and then stops, as the grains yellow and lose moisture in the process of "maturing". The mature or resting seed has been described by Villiers (1972) as being in a state of arrested development or quiescence, due to unfavourable environmental conditions.

Biochemistry of Germination

Germination has been defined as the resumption of growth activities which were suspended earlier (Amen, 1968). The transition from quiescence to germination undoubtedly involves a complex series of events yet to be fully understood. It has been established, however, that a number of these processes are also important in malting, which is essentially germination under controlled conditions of temperature and humidity.

Under optimum conditions for germination GA is synthesised in the

embryo (Yomo and Iinuma, 1966) and moves from there to the aleurone layers in the endosperm (Newman and Briggs, 1976). There is doubt over whether GA is synthesised in the embryonic axis (McLeod and Palmer, 1966) or in the scutellar epithelium (Briggs, 1972) but there is little doubt that this hormone causes gross physiological and biochemical changes in the aleurone layers. Physiological responses of the aleurone cells exposed to GA include the formation of cristae in the mitochondria (Srivastava and Paulson, 1968), the conversion of smooth to rough endo-plasmic reticulum organised in lamellar form (Jones, 1969), the formation of polysomes (Marcus, 1969) and the degradation of those ribosomes not assembled into polysomes (Payne and Boulter, 1969).

These changes appear to be in preparation for a period of synthesis and this is in accord with the observed synthesis of hydrolases (Higgins *et al,* 1976; Taiz and Honigman, 1976) by the aleurone cells in the presence of GA. Other hormones may also play a role in these changes. It has been reported that IAA* applied before GA to isolated aleurone layers accelerates the production of α-amylase activity by subsequent GA treatment (MacLeod and Palmer, 1969). The increase in α-amylase activity caused by GA in the aleurone appears to be due to a *de novo* synthesis (Varner and Ramchandra, 1964). Gibberellic acid also enhances the production of endo-β-glucanase by aleurone cells (Palmer, 1973), although this effect requires a higher GA concentration than that needed for α-amylase production. During malting, cell walls of the aleurone and the scutellar epithelium cells eventually degrade releasing GA and malt hydrolases into the sub-aleurone zone and the area of starchy endosperm at the scutellum (see Figure 1). In these tissues, bound, inactive β-amylase is converted to the free, active form, probably by a GA-induced protease (Grabar and Daussant, 1964). Endosperm breakdown or modification then proceeds further with the dorsal surface of the endosperm being digested before the ventral surface. This difference may be due to the angle at which the scutellum adheres to the starchy endosperm, such that the dorsal surface is nearer to the scutellar epitheliel cells, or to a channelling of GA preferentially through the provascular tissue in the embryo (MacLeod and Palmer, 1967).

Long chain polymers such as starch, organised into granules, and hemicelluloses and gums, incorporated into the endosperm cell walls, are broken down during modification to simple sugars. Each polymer is degraded by enzyme systems, usually with an endo- and an exo-enzyme component. For cell wall breakdown there may also be solubilising enzyme systems similar to those observed for cellulose breakdown by the cellulases of *Trichoderma viridae,* (Allison and Borzucki, 1978). In barley the solubilising system may include an endo-peptidase (Forrest and Wainwright, 1977). Endo-enzymes can attack the polymer almost anywhere within the molecule, causing a marked decrease in viscosity. In contrast exo-enzymes degrade the polymer, commencing at the outer chains and working stepwise along the polymer.

* Indole acetic acid.

Exo-enzymes are specific for a particular chemical bond and cannot proceed beyond a branch point in the molecular structure. For example the exo-enzyme β-amylase, which removes maltose units by hydrolysing α 1,4 linkages from the linear chains of amylose or amylopectin, is prevented from further attack by an α 1,6 linkage at, for example, an amylopectin branch point.

Five different β-glucanases have been identified in barley malt (Manners and Marshall, 1969). Three of these are endo-enzymes, hydrolysing combinations of β 1,3 and β 1,4 linkages (endo barley β-glucanase) or they are specific for β 1,3 linkages (endo- β 1,3 glucanase) or β 1,4 linkages (endo- β 1,4 glucanase). An exo-β-glucanase has been identified (Preece and Hobkirk, 1955) together with a number of β-glucosidases, which are not true exo-enzymes, (Manners and Marshall, 1969). The other gum and hemicellulose constituents, the pentosans, are also broken down by endo- and exo-systems working in unison. For example, exo- and endo-xylanases have been identified (Harris, 1962). In addition to the above systems there is a number of specific proteases and nucleases also secreted into the endosperm during malting.

The array of hydrolytic enzymes is further complicated by the existence of many in multiple form or isoenzymes. Isoenzymes can be defined as enzymes that act on the same substrate (e.g. α-amylases on starch) but differ from each other in biophysical attributes (e.g. electrical charge on the molecule). Studies in this laboratory on electrophoretic forms of β-amylase produced during malting have shown that the pattern of isoenzymes can change dramatically as malting proceeds (Allison, 1973). In related experiments, a partially degraded starch was prepared from the action of a fungal α-amylase on Lintner's starch (acid hydrolysed starch). After electrophoresis of extracts from two day old malts, the gel was divided into halves and one half incubated with undegraded and the other with partially degraded starch. Iodine staining revealed zones of amylase activity, and the α-isozyme pattern on degraded starch differed from that on undegraded starch. The former pattern was typical of that observed from the action of six day old malts on undigested starch. These results indicate that more of certain α-amylase isozymes may be produced as starch breakdown progresses.

The relative importance of the various hydrolases, including isoenzyme forms in the malting process has yet to be determined. There is evidence, however, that α-amylase initiates the attack on starch granules (Dunn, 1974) and when breeding objectives for malting quality are defined, high α-amylase activity is usually included (Ellis *et al*, 1979). In breeding for high diastase barleys, high β-amylase activity is one objective, as diastatic activity appears to be mainly due to β-amylase. Breeding lines identified as potential high diastase barleys are also monitored for α-amylase, in case the latter enzyme should limit full expression of diastatic activity. Limit dextrinase (the starch debranching enzyme which hydrolyses α1,6 links between glucose molecules in starch) is not routinely measured, as studies on sugars in whisky

worts by Bathgate *et al* (1978) demonstrated that sufficient limit dextrinase survives kilning and mashing to convert low molecular weight branched dextrins to fermentable sugars. The production of β-glucanases and pentosanoses is not included among our malting quality objectives, as the part these enzymes play in modification remains unclear, and most of them are heat-labile and lose all activity in the first five minutes of mashing (Scott, 1972b). Thus the biochemical objectives when breeding for high diastase must include high diastase activity (which is mainly β-amylase activity) and at least moderately high α-amylase activity. Agronomic objectives include yield and disease resistance. In Scotland earliness is also an important consideration.

Breeding for High Diastatic Power

Once the objectives of a high diastase breeding programme had been specified, then appropriate methods for measuring the concentration of the enzymes concerned, including screening methods, could be developed. In addition, sources of genetic variation for diastase content were investigated with the aim of introducing suitable genotypes into a pedigree breeding programme. This investigation was extended to include studies on the mode of inheritance of diastase content.

THE DEVELOPMENT OF APPROPRIATE METHODS OF ESTIMATION

In an initial attempt to develop a screening system, the gel diffusion assay of Briggs (1962), in which α-amylase digests a β limit dextrin substrate held in gel form, was modified for the estimation of diastase using a starch substrate (Hayter and Allison, 1972). The extent of the digested area in both of these tests was logarithmically, rather than linearly, related to enzyme concentration and the tests were thus not sensitive enough for selection purposes. The more sensitive, but lengthy, micromalting method was developed, essentially according to the procedures described by Whitmore and Sparrow (1957). Diastatic activity of cold water extracts of malts was measured according to the Recommended methods of the Institute of Brewing (IB). That is the diastatic power (DP) was estimated in extracts of green malt by the manual Fehling's titration. α-Amylase activity was measured initially by Preece's (1947) method but subsequently by the IB method, with the activity expressed as dextrinising units. With these methods it was only possible to assay the DP and α-amylase activity of eight samples per day. A changeover from green to kilned malt samples which were stored in hermetically sealed containers, allowed an increase in throughput of malted samples. The acquisition of Autoanalyser facilities and the acceptance, by the IB of diastase measurements using the ferricyanide method meant that the automated methods of Scharoun and Saletan (1965) for DP and Trachman and Saletan (1970) for α-amylase (Figure 2 a and b) could be used. These are based on methods approved by the American Society of Brewing Chemists.

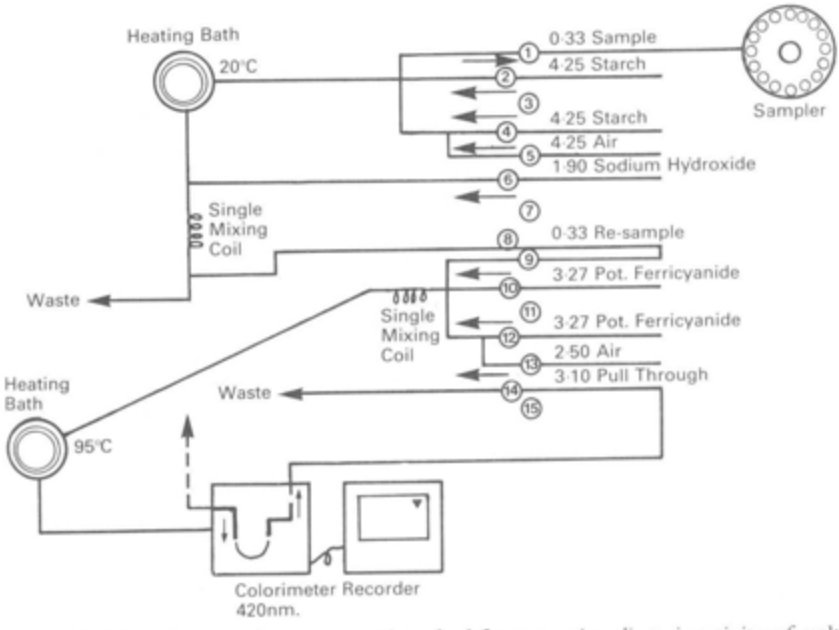


Figure 2a. Flow diagram of an automated method for measuring diastatic activity of malts.

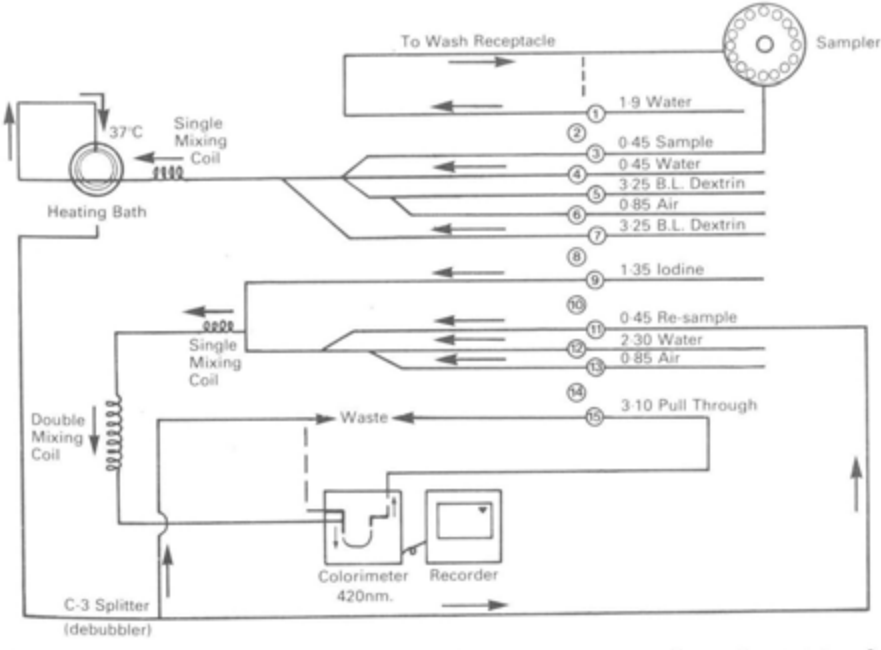


Figure 2b. Flow diagram of an automated method for the measurement of α-amylase activity of malts.

Comparative tests showed that, for DP, the automated method was related to the IB manual method but with one important advantage. In the manual method, y (the manual DP in degrees Lintner using Merck starch), was curvilinearly related to the enzyme concentration x (expressed in mg Wallerstein β-amylase/100ml 0·1% NaCl) such that $y = 4{\cdot}44 + 0{\cdot}812x - 0{\cdot}00066x^2$, when y is in the range 50° to 250° Lintner. This is the range of sensitivity of the manual method. In the automated method, peak heights of traces on the pen recorder chart, were linearly related to enzyme concentrations, even at levels higher than 1,000 mg, whereas in the manual method a plateau was reached when x increased above 500 mg. Determinations of DP by automated analysis were not, therefore, expressed in degrees Lintner but were calculated as a proportion of that of the nearest enzyme standard solution with a DP of 250°L. These measurements are termed DP proportion (DPP) (Figure 3 shows an example of chart recorder output from which DPPs may be calculated).

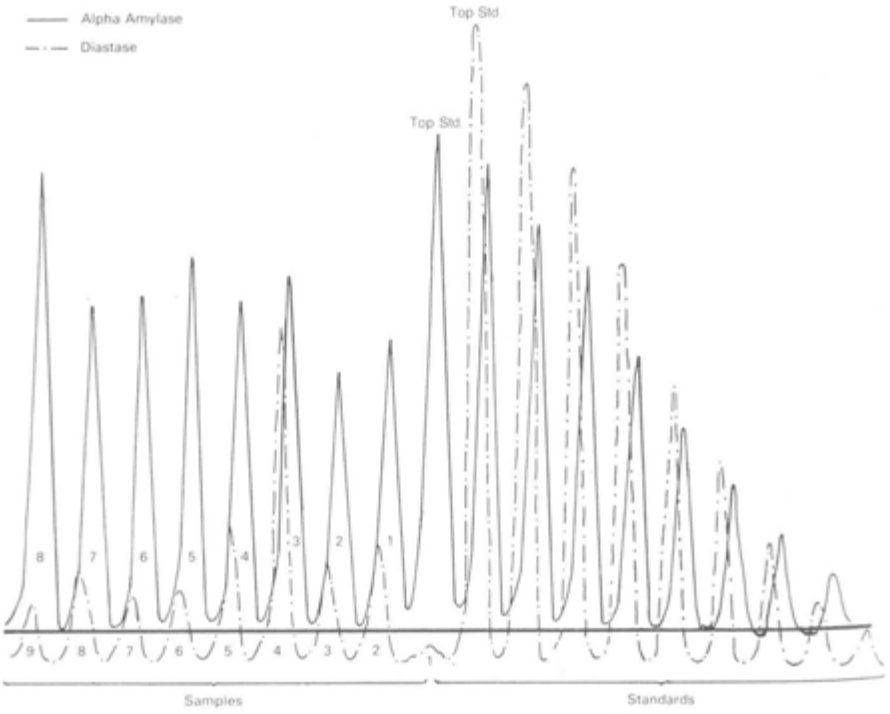


Figure 3. Peaks of diastatic and α-amylase activity measured on the manifolds shown in Figs. 2a and b.

The automated method for α-amylase determination and the manual method gave results which were linearly related to enzyme concentration, such that α-amylase proportion (AAP) could be directly equated with dextrinising units (DU) (1·0 AAP = 100 DU = 20 mg Sigma type-IV α-amylase). Fast, accurate measurements of enzyme activity could now be made using Autoanalyser methods, but the process of micro-malting was still time-consuming and a source of uncontrolled biological variation.

A search was made, therefore, for tests which could be applied to the raw grain. It had been established that DP could be predicted by measuring β-amylase activity in papain extracts of raw barley grains ground in a hammer mill (Sallans and Anderson, 1938; Meredith, *et al*, 1942; Bendelow, 1964). This test was modified by Allison and Swanston (1974) so that papain extracts of small samples of flour (0·25 g) could be assessed for predicted DP on the autoanalyser. It has not yet proved possible to develop a technique for the prediction of α-amylase, which is synthesised *de novo* in the germinating grain.

SOURCES OF SUITABLE GENETIC VARIATION

Barley varieties, such as Olli and Pirkka (for pedigrees and provenances see Riggs and Hayter, 1972), have been imported by the grain whisky industry for a considerable time, because these varieties are high in DP and can therefore be used for the manufacture of diastatic malts. In 1968 and 1969 variety trials were conducted at a number of sites in Scotland comparing Olli and Pirkka with commercial varieties such as Ymer, Cambrinus and Maris Baldric. These trials demonstrated that Olli and Pirkka would not produce acceptable yields, which was not unexpected since both were six-row varieties adapted to rather different conditions from those which prevail in Scotland. Both varieties were tall and weak strawed, extremely mildew susceptible and very early so that they were preferentially attacked by birds. For these reasons, these varieties gave low yields, 50 to 75 per cent of that of Ymer. The grain samples derived from Olli and Pirkka were nevertheless suitable for the production of diastatic malts, and had very high levels of DP and α-amylase.

Spring barley varieties grown commercially in Scotland are exclusively of the two-row type and the introduction of genetic variation from six-row backgrounds would pose problems which are widely recognised and have been analysed by Riggs and Kirby (1978) and Kirby and Riggs (1978). A search for sources of variation in two-row barleys was therefore made and a number of potentially usable sources was found. Most of these proved to have only intermediate levels of DP and only the variety Akka had high DP (Hayter and Riggs, 1972). Akka, however, is low yielding and there is a need for plant breeders to produce varieties combining high DP with satisfactory yield. Akka is being used extensively in the pedigree breeding programme directed to this end. Other relatively unadapted sources of high DP are considered in the sections on polymorphisms and high lysine barleys.

Concurrently with the development of suitable biochemical methods of measurement and the search for suitable genetic variation, studies were undertaken of the mode of inheritance of the levels of activity of the enzymes concerned. The early studies concentrated on the relative importance of the effects of genotype, environment and G × E interaction. Hayter and Riggs (1972) demonstrated, in a factorial fertiliser trial, that the levels of nitrogenous fertiliser were important in the determination of DP, α-amylase and grain nitrogen contents. The effects of phosphatic and potassic fertilisers were less important. In subsequent variety-nitrogen trials DP was shown to be positively correlated with both α-amylase and grain nitrogen levels although the latter two variates were not significantly correlated with each other. It was hypothesised that these relationships stem from differences in the production of α- and β-amylases in the germinating grain. β-Amylase is present in the resting grain and is converted from a predominantly bound form to a free form during germination. Levels of β-amylase might be expected therefore to be related to the nitrogenous fertilisation of the growing crop. β-Amylase activity contributed largely to DP. On the other hand α-amylase is synthesised *de novo* in the germinating grain and may be related not so much to previous nitrogen fertilisation as to the genetic potential to synthesise the enzyme. Interestingly, Akka was shown to contain only moderate levels of α-amylase and both enzymes appear to be present, at high levels, only in six-row barleys.

A large diallel experiment was grown in 1970 and 1971 (Riggs and Hayter, 1972, 1973, 1975) to investigate a number of characteristics including DP and α-amylase levels (Hayter and Riggs, 1978). In the case of DP, within family variances were heterogeneous and highly correlated with family means. This invalidated the genetic assumptions for diallel analysis but could be removed by appropriate transformation of the data. However, the conclusions reached by analysis of the transformed and untransformed data were similar. Graphical analysis of array variances and covariances indicated the presence of non-allelic interactions. Six-row genotypes occupied positions which suggested that high DP was determined by dominant genes. Analysis of the two-row genotypes alone did not remove all of the non-allelic interactions but suggested that many stemmed from basic differences between six-row and two-row genotypes. Analysis of variance of the diallel table (Hayman, 1954), demonstrated the absence of maternal (c) effects and other reciprocal differences. Both additive and non-additive genetic variances were detected, the non-additive being due to directional dominance (b_1) for increasing DP, asymmetry of gene distribution (b_2) and interactions between specific genotypes (b_3). A high level of overall heterosis was observed. The effects of both general and specific combining abilities were significant but only GCA effects were consistent over blocks and seasons.

For α-amylase levels the basic additivity plus dominance model was adequate. Graphical analysis indicated partial dominance when six-row and two-row genotypes were included and in two-row genotypes considered alone. Six-row genotypes again occupied position on the graph indicating an excess of dominant genes. Although analysis of variance demonstrated the absence of maternal effects, variation due to reciprocal differences not attributable to c was significant in 1971. Both additive and non-additive genetic variances were detected and the non-additive variances were due to directional dominance (b_1), asymmetry of gene distribution (b_2) and interactions between specific genotypes (b_3). In the two-row genotypes analysed alone, non-additive effects were exclusively due to directional dominance. Dominance in the six-row plus two-row genotypes, was ambidirectional but predominantly for increased α-amylase. Only low levels of heterosis were observed. The effects of general and specific combining abilities were significant but, as for DP, only GCA effects were consistent over blocks and seasons. For both DP and α-amylase, GCA effects were positively correlated with parental means.

THE DEVELOPMENT OF A PEDIGREE BREEDING PROGRAMME

The genetic analyses confirmed the basis on which the pedigree breeding programme had already been started. Parents were chosen with high mean expressions of DP or α-amylase or both and crosses were made which gave rise to populations segregating for recombinations of enzymatic and agronomic characters. Considerable improvement was possible in DP alone using pair-crosses of exclusively two-row parents, particularly Akka. Progress with the cross Midas × Akka (BH3) and the reciprocal (BH4) has been reported (Hayter and Allison, 1976). Material from this cross will be submitted for National List Trials in 1980. Lines which combine the high DP of Akka with the agronomic properties of Maris Mink have been selected from the crosses Akka × Maris Mink and Akka × Maris Mink^2. Material from these crosses will also be submitted for National List Trials in 1980.

Although Akka, Midas and Maris Mink have only modest levels of α-amylase it was interesting to note that in some lines from these crosses transgressive segregation was observed for increased α-amylase. To achieve high DP combined with high α-amylase it was thought necessary to use six-row parents. Attempts to derive commercial lines from the initial six-row × two-row crosses proved unsuccessful, as expected. In addition to the short-comings of the six-row parent, which were not overcome in one cycle of crossing, it was not possible to select six-row or two-row types which followed normal physiological patterns of development. Further crossing was necessary and attempts to improve the enzymatic and agronomic properties are continuing. It may eventually prove quicker to assemble improvements in DP and α-amylase made separately in two-row crosses than to incorporate improvements from a six-row into a two-row background. Meanwhile, attempts are also being made to introduce the high DP properties

of the six-row spring barleys into six-row winter barleys which are already in commercial use. Breeding for this objective commenced in the winter of 1978.

Mutation Breeding

As an alternative to the conventional pedigree breeding approach, discussed in the preceding section, an attempt was made to select for DP in well-adapted varieties using a combination of mutagenesis and biochemical screening. The production of enzymes by the aleurone cells in response to GA is inhibited by abscisic acid (ABA). Selection for resistance to ABA inhibition might therefore increase GA production and thus lead, in turn to an increased diastase production during germination. Pilot experiments (Hayter and Allison, 1976) indicated that this was reasonable as an ABA concentration of 5×10^{-4} molar inhibited the germination of Ymer (a low DP barley) in petri dishes, whereas the high DP variety Olli germinated, albeit slowly, in the presence of the inhibitor. Although this difference in germination may have had trivial causes e.g. a reduced uptake of ABA by Olli, it seemed likely that ABA could be used to screen for inhibitor-resistant, high diastase barley.

Variation was induced in a population of seeds of the variety Ymer by treating it with ethyl methane sulphonate (EMS), according to the method of Mikaelson *et al* (1968). When these experiments started, Ymer was widely grown in Scotland, although it has subsequently become outclassed. A total of 18,000 grains harvested from plants grown from treated seed (M_1) were screened in the first pilot experiment and 23 M_2 individuals were selected that germinated well despite the inhibitor. The selected mutants were grown on, and micromalted samples of M_4 seed showed considerable variation for DP and α-amylase. One line, Mutant 16 had a relatively high diastatic activity (Table 21). Further tests revealed, however, that DP in this mutant strongly

TABLE 21

Grain nitrogen, DP and α-amylase contents of Ymer mutants following EMS treatment and screening in the presence of ABA.

Variety	*Grain N per cent of dry matter*	*DP (Green malt, °L)*	*α-amylase (Green malt, °L)*
Olli (six-row)	2·31	327	34·1
Golden Promise	2·13	216	28·7
Ymer	2·02	184	27·6
Mutant 5	2·49	239	37·4
Mutant 16	2·26	291	27·6
Remaining mutants	2·12	175	26·5

depended on the environment. When environmental conditions were unfavourable for nitrogen uptake (resulting in grain nitrogen values below 2·0 per cent) the DP of mutant 16 was not significantly different from that of

Ymer. Under conditions leading to high grain nitrogen, this mutant takes up more nitrogen than Ymer with a consequent increase in DP, the increase being specifically in "free" β-amylase. It is known that β-amylase activity is first detected in developing grains at about fourteen days after anthesis (Duffus and Rosie, 1973) and a GA-like hormone is also synthesised at this time (Mounla and Michael, 1973). Mutant 16 may therefore produce more of a GA specific for free β-amylase synthesis.

This selection technique was also applied to populations of Maris Mink and Universe which had been treated with EMS. From ABA screenings of 100,000 M2 grains of each variety and subsequent testing at later generations, five ABA-resistant Maris Mink mutants were selected. All five were similar to the Ymer mutant 16 in that they took up more nitrogen into the grain when there was excess nitrogen. The increase in diastase observed, due to this preferential uptake of nitrogen, is intermediate between the low diastase of Maris Mink and that of a typical high diastase barley e.g. Akka. At lower nitrogen levels (below 2·0 per cent) the diastase levels of three mutants were not different from that of the parent. However, two mutants, MM22 and MM23 were consistently higher in DP than the parent even at lower nitrogen levels. Unfortunately MM23, with the greatest DP increase was a double dwarf genotype with the prostate habit of Maris Mink during early growth combined with an erectoides phenotype at later growth stages, and this mutant had a relatively poor yield. The second line MM22 was also significantly shorter than Maris Mink (by approximately seven centimetres) and this line also yielded less than the parent. However, one mutant line, MM39, a single plant reselection from M_6 showed an increase in DP to approximately the Golden Promise level, when conditions favoured high grain nitrogen and this line also yields well. This line has been submitted for National List Trials in 1979.

Since the ABA screening system is essentially a germination test, some variants may germinate well and be ABA-resistant because of changes in the endosperm, rather than having altered enzymatic properties. From studies on the electrical energy required to mill barley (Allison *et al,* 1976), it is known that barleys which malt readily, usually have "soft" endosperms and hence low milling energies. In a survey of ABA-resistant mutants one line, MM24, showed very low milling energy, less than that of Golden Promise, and thus is a possible parent for an attribute of the endosperm that relates favourably to malting quality.

The mutation with screening system approach to the production of high DP did not completely fulfil our expectations, as the mutant lines with the highest DP yielded less well than the parent, Maris Mink. A line with intermediate DP and satisfactory yield was obtained, however, and certain mutants e.g. the double dwarf and MM24 with a mutation affecting grain hardness, are useful sources of variation for the main-line breeding programmes.

As a preliminary to the mutation and screening of current varieties, the number of amylases produced under GA control was investigated. During the course of this work the observation was made that the majority of European and Canadian barleys tended to differ in forms of β-amylase present in malts. The genetical control of this polymorphism and how it relates to DP and malting quality was explored further.

Polymorphisms

In recent years electrophoresis has proved a useful tool for the detection and analysis of isoenzyme variation, and multiple forms of starch-degrading enzymes have been demonstrated in barley (Frydenberg and Nielsen, 1966; Bilderback, 1971; Allison, 1973). Differences in zone migration observed for the heat-stable α-amylases of barley malt (Frydenberg and Nielsen, 1966; Fedak and Rajhathy, 1971) were shown to be controlled by co-dominant alleles at one locus (Frydenberg and Nielsen, 1969). A second type of polymorphism occurs, however, in which isoenzymes with the same electrophoretic mobility, differ in activity, such that one band of a pair with similar migration rates may stain more strongly, and thus have higher activity (Schwarz, 1962). Allison (1973) demonstrated this kind of polymorphism for malt β-amylase of some European and American cultivars, as shown by the examples of zymograms in Figure 4. The four bands nearest the cathode are identified as β-amylases as they are heat-labile, stain pink with iodine and do not degrade β-limit dextrin.

In Ymer (zymogram Y) β-iso-amylases 3 and 4 lose activity in the later stages of germination more rapidly than the corresponding bands in Olli (zymogram O), whereas β-iso-amylase 6, is more active in Ymer than in Olli at all stages of germination. The β-amylase forms in zymograms O and Y are called sd1 and sd2, respectively, to agree with the nomenclature proposed by Finnegan (1969). The F_1 heterozygotes also have distinctive isozyme patterns as exemplified by zymogram OY where Olli was the female parent and zymogram YO which is for the reciprocal cross. β-Iso-amylases in zymogram OY are intermediate in activity between that of corresponding zones in zymograms O and YO, while β-iso-amylases 4 and 5 activities are between those of the corresponding bands in zymograms OY and Y. That β-iso-amylase 6 in zymogram YO is not intermediate in activity is due to the zymogram Y being at a later germination stage and consequently, showing some loss of activity. From studies on F_2 segregation ratios it was concluded that β-iso-amylases 3 to 6 are controlled by a pair or pairs of alleles acting without dominance, and the differences between F_1 grains strongly suggested a gene dosage effect typical of that found for endosperm genotypes, which are triploid with two maternal genomes but only one of parental origin.

Amylase activity is not confined to the germinating grains as both α and β-amylase have been shown to be present during grain development, with

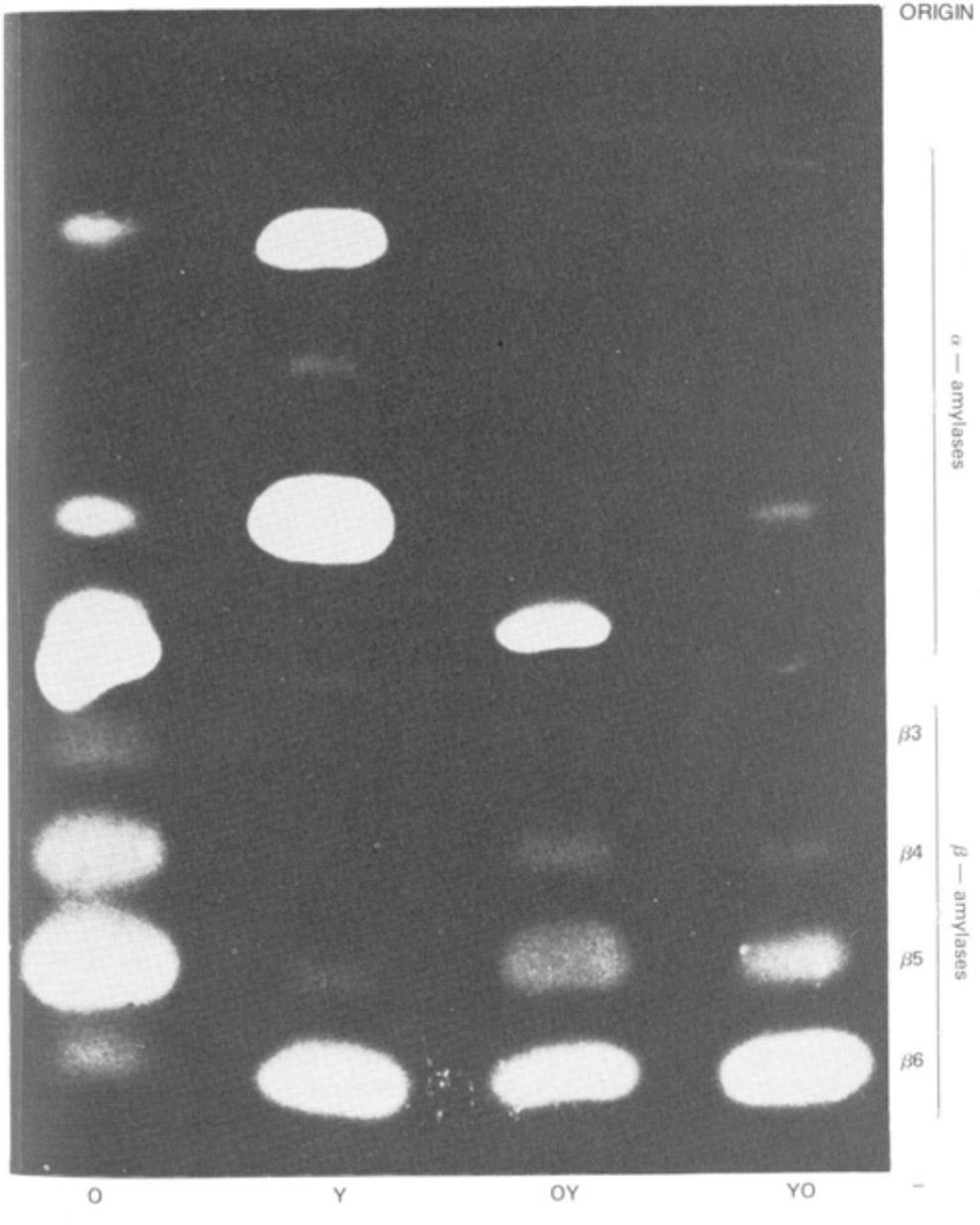


Figure 4. Electrophoretic separation of amylases from single grains of the cultivars Olli (O), Ymer (Y), the F1 hybrid with Olli as female parent (OY) and the F1 hybrid with Ymer as female parent (YO), + is the anode and − is the cathode.

β-amylase activity being retained until maturity (May and Buttrose, 1959; Laberge *et al*, 1971). As barley grains ripen, β-amylases seem to increase in molecular weight (Stoddart, 1971). This may be due either to a polymerisation of β-amylase subunits, or to a complexing of β-amylase with other proteins, causing a reduction in electrophoretic mobility.

Allison and Ellis (1973) reported different forms of this developmental sequence. These are shown diagrammatically in Figure 5. Different forms are

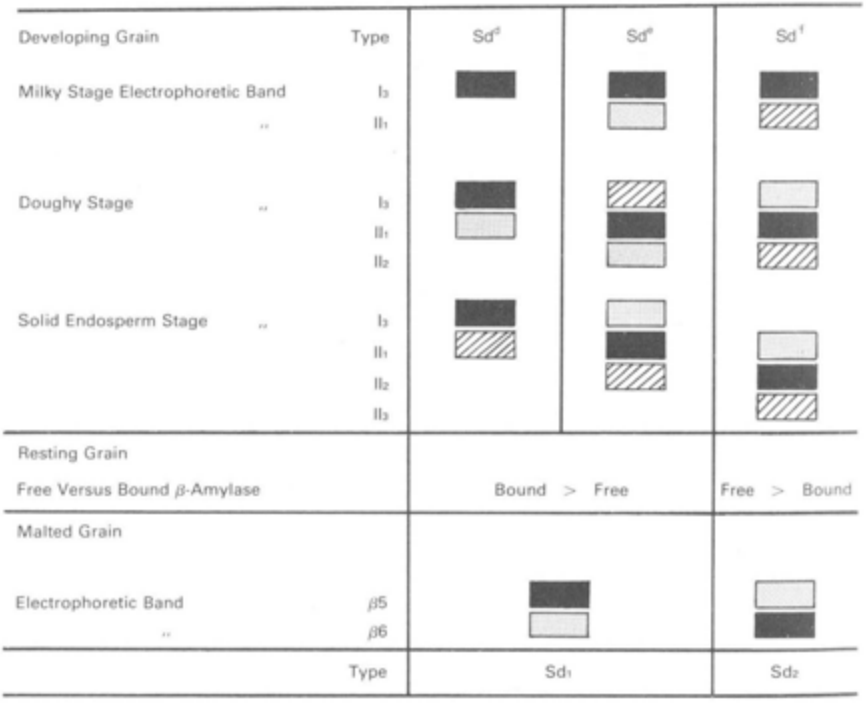


Figure 5. Diagrammatic summary of the β-amylase polymorphisms observed in developing, resting and germinating grains of barley.

— high β-amylase activity in an electrophoretic band.

— moderately active β-amylase electrophoretic band.

—β-amylase electrophoretic band with low activity.

identified by the position of the band with highest β-amylase activity, and crosses were made between the varieties Golden Promise (sd^f zymotype) and Pirkka (sd^d zymotype). F_1 hybrids had two bands with high activity and thus exhibited both of the sd^f and sd^d zymotypes. It was concluded that this phenotype was determined by two co-dominant alleles. A total of 97 F_1 plants was typed for β-amylase bands and there were 26 sd^d zymotypes, 52 heterozygotes and nineteen sd^f zymotypes which fits a 1:2:1 ratio (chi^2 = 1·52, $0{\cdot}5>P>0{\cdot}3$). The relationships of these forms to free versus bound β-amylase is also shown in Figure 5.

Free Versus Bound β-Amylase

At least two forms of β-amylase are present in the resting grains of barley, a water-soluble free or active form and a latent form which can be rendered active by papain or other reducing agents possessing thiol groups. Sallans and Anderson (1938) found two levels of free β-amylase among Canadian varieties at approximately 22 per cent and 40 per cent of total β-amylase activity. More recently Sandegren and Klang (1950) and Bendelow (1964) confirmed the presence of two distinct groups, although the exact percentages of total activity varied according to the method of extraction used. Bendelow further showed that the ratio of free to total β-amylase was inherited in a simple Mendelian fashion independent of the level of total β-amylase and suggested that high levels of free β-amylase were important in the selection of Canadian malting barleys.

During grain ripening, a proportion of β-amylases is converted to a bound form (Shinke and Mugibayashi 1971) and on germination β-amylase is converted back to a free, active form under the control of gibberellic acid. Allison and Ellis (1973) demonstrated a link between developing grain and malt polymorphisms and it seemed reasonable to expect that the mature grain polymorphism might also be correlated with the other two.

Allison and Swanston (1974) tested 46 cultivars for free and total β-amylase contents in the mature grain and the grains were germinated and typed for malt electrophoretic pattern. It was found that all cultivars with the electrophoretic pattern sd1 had free β-amylase levels below 50 per cent of the total β-amylase activity (and with only two exceptions, below 42 per cent), while all of the sd2 types had free β-amylase levels above 50 per cent and all except two had levels which exceeded 60 per cent. The differences between sd^d and sd^e groups observed in the developing grain, which were not reflected in differences in malt electrophoretic patterns were also not detectable in relation to ratio of free:total β-amylase in the mature grain. Thirteen of the genotypes were tested for diastatic power and a high correlation was observed ($r = +0{\cdot}95$, $df = 11$) between total β-amylase and DP, but neither DP nor total β-amylase was correlated with the ratio free to total β-amylase.

Within both the sd1 and the sd2 groups, a range of total β-amylase levels was observed, but the ratio of free to total β-amylase remained constant. Thus, within each group, free β-amylase and total β-amylase were highly correlated and the two factors might be found to be linked if they could be studied without the additional complications of diverse genetic backgrounds. Electrophoretic typing would have considerable potential as a prediction test as it could be applied to single endosperms and could be used at very early stages in a breeding programme. In addition, since homozygotes and heterozygotes could be distinguished, the character being measured could be readily fixed in the homozygous state.

Several crosses were studied and no instances were recorded of sd1 types having a high free to total β-amylase ratio, nor low ratios being associated

with sd2 types. In the cross Akka (sd2, high diastatic power) × Universe (sd1, low diastatic power) it was observed that all progeny with the sd2 electrophoretic pattern had higher levels of diastatic power than the sd1 types. Measurements were made on bulks from an F_4 trial which had been advanced two generations from single plant selections at F_2. Lines which were heterozygous for sd-type had diastatic powers intermediate in level between sd2 and sd1 types. However, when F_3 rows from the cross Conquest (sd1, high diastatic power) × Maris Mink (sd2, low diastatic power) were measured for predicted diastatic power after papain extractions it was observed that higher levels of β-amylase activity tended to be associated with the sd1 genotypes. There seems therefore to be a tendency for the parental combination of sd type and level of DP to be recovered in the progeny of bi-parental crosses and the gene controlling sd type is probably linked with one or more of the genes controlling the level of DP. A greater range in activity was observed than for the Akka × Universe cross, and was associated with a wider range in grain nitrogen content. There was some overlap in distribution, as those sd1 genotypes which had lowest nitrogen levels had lower β-amylase levels than sd2 types with a high nitrogen content.

It was concluded that high levels of β-amylase activity or diastatic power were associated with genotypes which take up the highest levels of available nitrogen and synthesised the highest levels of particular proteins. There appeared to be some link between β-amylase activity and electrophoretic pattern which related to the second of these functions. This was not a pleitropic effect of a particular gene as the increase in enzyme activity could be associated with either sd-type.

During investigation of a third cross between the varieties Akka and Feebar which both have high levels of diastatic power, but which differ in elec-

TABLE 22

β–Amylase activity, grain nitrogen content and grain weight of the mature grains of some two- and six-row cultivars and of the F_4 progeny from a cross between Akka and Feebar.

	Grain Weight (mgs)	*Nitrogen per cent*	*β-Amylase (AA units)*
Cultivar			
Akka	56·4	1·86	1,292
Feebar	44·2	2·20	1,109
Conquest	46·9	2·23	1,347
Goldfield	45·8	2·17	914
Maris Mink	47·4	2·07	629
Olli	40·4	1·94	1,185
Ymer	55·1	1·96	478
Progeny			
AFS 3	63·0	2·83	2,879
AFS 11	63·3	2·69	1,950
AFS 28	66·2	3·10	2,810
Mean of 32 progeny	53·0	2·35	1,306

trophoretic pattern, several lines were observed to have levels of β-amylase activity greatly in excess of either parent (Table 22). This indicated that different mechanisms exist to bring about high levels of starch degrading enzyme activity and these may complement each other to enhance enzyme levels. As this could lead to an alternative approach to breeding for high diastatic barleys, these lines are being studied further.

High Lysine Barleys

Morphs, or variants, for quality components may occur naturally in populations, or they can be induced by mutation. Munck (1969) selected a variety with increased lysine content, from a barley collection, by means of a dye-binding test. The same screening technique was used by Doll (1972) to select high lysine lines from mutated populations. One of these mutants, Risø 1508, had an increase in water and salt-soluble proteins (albumins and globulins) of 47 per cent and a reduction in prolamin of twenty per cent compared to the protein balance of the parent, Bomi Abed. Since β-amylase is one of the albumin proteins, it seemed likely, that high lysine barleys could be useful sources of high DP. For most of the high lysine mutants, this was not the case. Risø 1508, with the highest grain lysine content, produced very low β-amylase activity, below that of Glacier (Ac 38) previously shown to be poor in β-amylase (Allison and Swanston, 1974). However one mutant, Risø 56, and the high lysine barley, Hiproly, both had diastase values equivalent to those of Akka, a known high distase barley.

These differences in enzyme activity of the lysine mutants are in accord with an electrophoretic investigation (Kreft *et al,* 1976) of the water and salt-soluble proteins of Hiproly and a sister line, in which the concentration of some proteins was increased and of others decreased in the high lysine line. Thus, the reported increase in albumins and globulins appears to be a net increase. A comparison (Allison, 1978) of the electrical energies required to mill the high lysine barleys also showed considerable variation with five mutants having relatively "soft" endosperms typical of barleys that malt readily e.g. Ark Royal. High lysine mutants are therefore potentially useful sources of variation for high diastase and malting quality breeding programmes.

Breeding for Malting Quality

A greater proportion of the barley crop is malted in Scotland than in England and Wales. As a result maltsters have played a large part in determining the barley varieties grown in Scotland. Two varieties, Golden Promise and Midas account for most of the crop area and since neither variety now has effective mildew resistance, and therefore require fungicide treatment, a rapid evolution of fungicide tolerant pathotypes could cause serious difficulties.

When breeding for malting quality was started at SPBS in 1974 the requirements for malting quality in Scotland were examined. Apart from the special requirement for high diastase barley there are two markets for malting barley, namely brewers and malt distillers. Traditional malting quality, defined as high levels of hot water extract and intermediate levels of total soluble nitrogen, would be satisfactory for either use. Distillers might purchase grain with higher nitrogen content than brewers and might also be interested in total spirit yield. The development of the malting quality programme has paralleled that of the high diastase programme in that we have investigated (1) possible selection methods, (2) sources of genetic variation, (3) the manipulation of genetic variability and (4) crosses for a pedigree programme.

THE DEVELOPMENT OF SCREENING METHODS

The first method used in the selection of possible parents was a modification of Whitmore and Sparrow's (1957) micromalting procedure. The steeped grain was floored in 500 ml conical flasks, rather than in boiling tubes, and kilning was carried out at 60°C for 48 hours. This low kilning temperature was introduced after consultation with maltsters and reflects industrial practice in the production of distilling malts. Malt analysis is carried out according to the IB Recommended Methods (1971) with modifications to increase throughput. Cold water and hot water extracts were determined with a refractometer and the automated methods for the determination of α-amylase and diastatic power, mentioned in the section dealing with high diastase barley breeding, were used.

For a number of reasons, including the need to use sixty grams of grain, the lengthy process time, and the desirability of genetic homogeneity of the material being tested (Sparrow, 1970), micromalting cannot be used to assess early generation material. Thus, in F_3 and F_4 generations no selection was possible except for screening of grain nitrogen content by autoanalyser methods. This situation was transformed by the introduction of rapid screening methods which required only small amounts of grain. Ellis *et al* (1979) investigated the usefulness of Palmer's sedimentation method (Palmer, 1975), β-glucan measurements (Greenberg & Whitmore, 1974) and milling energy requirement (Allison *et al*, 1976). The ability to measure, simultaneously, grain nitrogen and β-glucan content by the use of infra-red reflectance from milled barley samples (Allison *et al*, 1978) has further speeded up the screening of early generation material. Details of these methods are considered in the following sections.

The current selection methods at SPBS are illustrated in Figure 6. The application of milling energy, grain nitrogen and β-glucan measurements in early generation selection may also have benefits other than earlier selection for malting quality. For example, if a marginal lack of disease resistance or physiological adaptation resulted in poor grain filling the screening methods would also reject those genotypes.

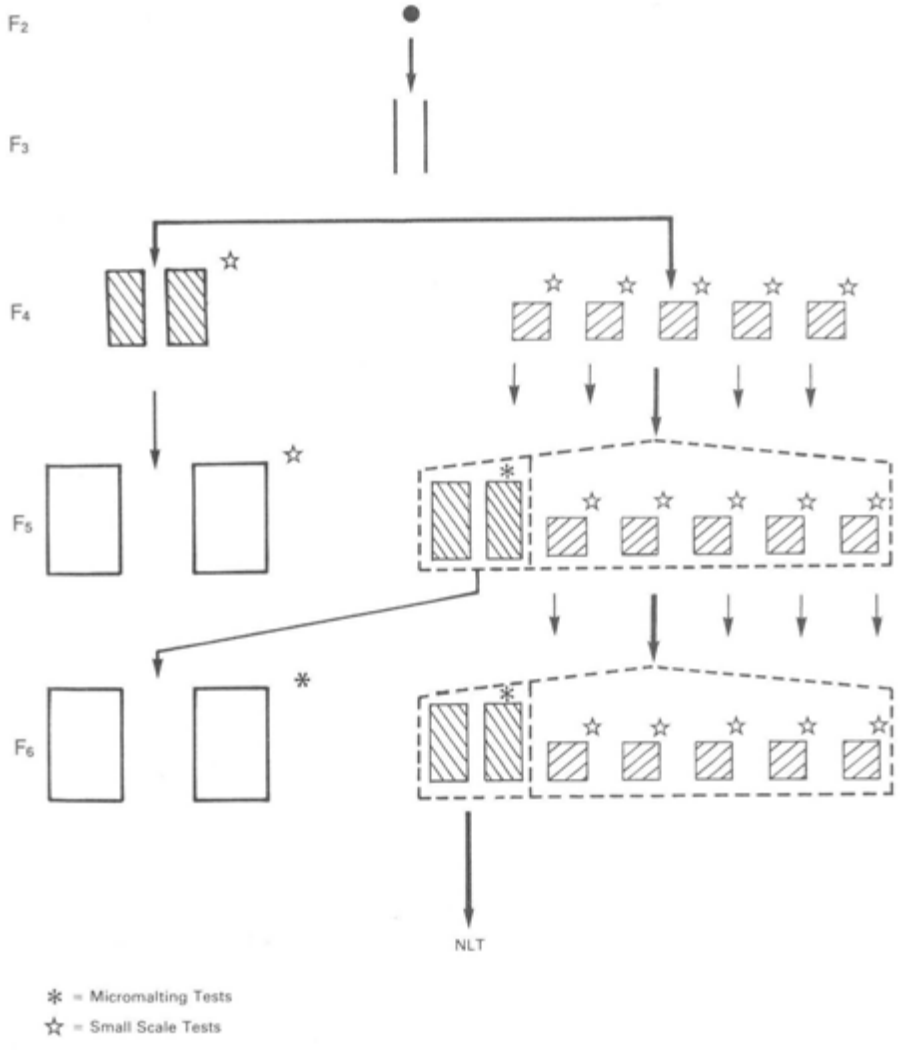


Figure 6. Current barley breeding scheme used by the S.P.B.S. Cereals Department.

- ● F_2 single plant selection
- II F_3 rows
- ▨ Small plot trials
- □ Large plot trials
- ▨ Progeny plot

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THE DEVELOPMENT OF SCREENING METHODS

The first method used in the selection of possible parents was a modification of Whitmore and Sparrow's (1957) micromalting procedure. The steeped grain was floored in 500 ml conical flasks, rather than in boiling tubes, and kilning was carried out at 60°C for 48 hours. This low kilning temperature was introduced after consultation with maltsters and reflects industrial practice in the production of distilling malts. Malt analysis is carried out according to the IB Recommended Methods (1971) with modifications to increase throughput. Cold water and hot water extracts were determined with a refractometer and the automated methods for the determination of α-amylase and diastatic power, mentioned in the section dealing with high diastase barley breeding, were used.

For a number of reasons, including the need to use sixty grams of grain, the lengthy process time, and the desirability of genetic homogeneity of the material being tested (Sparrow, 1970), micromalting cannot be used to assess early generation material. Thus, in F_3 and F_4 generations no selection was possible except for screening of grain nitrogen content by autoanalyser methods. This situation was transformed by the introduction of rapid screening methods which required only small amounts of grain. Ellis *et al* (1979) investigated the usefulness of Palmer's sedimentation method (Palmer, 1975), β-glucan measurements (Greenberg & Whitmore, 1974) and milling energy requirement (Allison *et al*, 1976). The ability to measure, simultaneously, grain nitrogen and β-glucan content by the use of infra-red reflectance from milled barley samples (Allison *et al*, 1978) has further speeded up the screening of early generation material. Details of these methods are considered in the following sections.

The current selection methods at SPBS are illustrated in Figure 6. The application of milling energy, grain nitrogen and β-glucan measurements in early generation selection may also have benefits other than earlier selection for malting quality. For example, if a marginal lack of disease resistance or physiological adaptation resulted in poor grain filling the screening methods would also reject those genotypes.

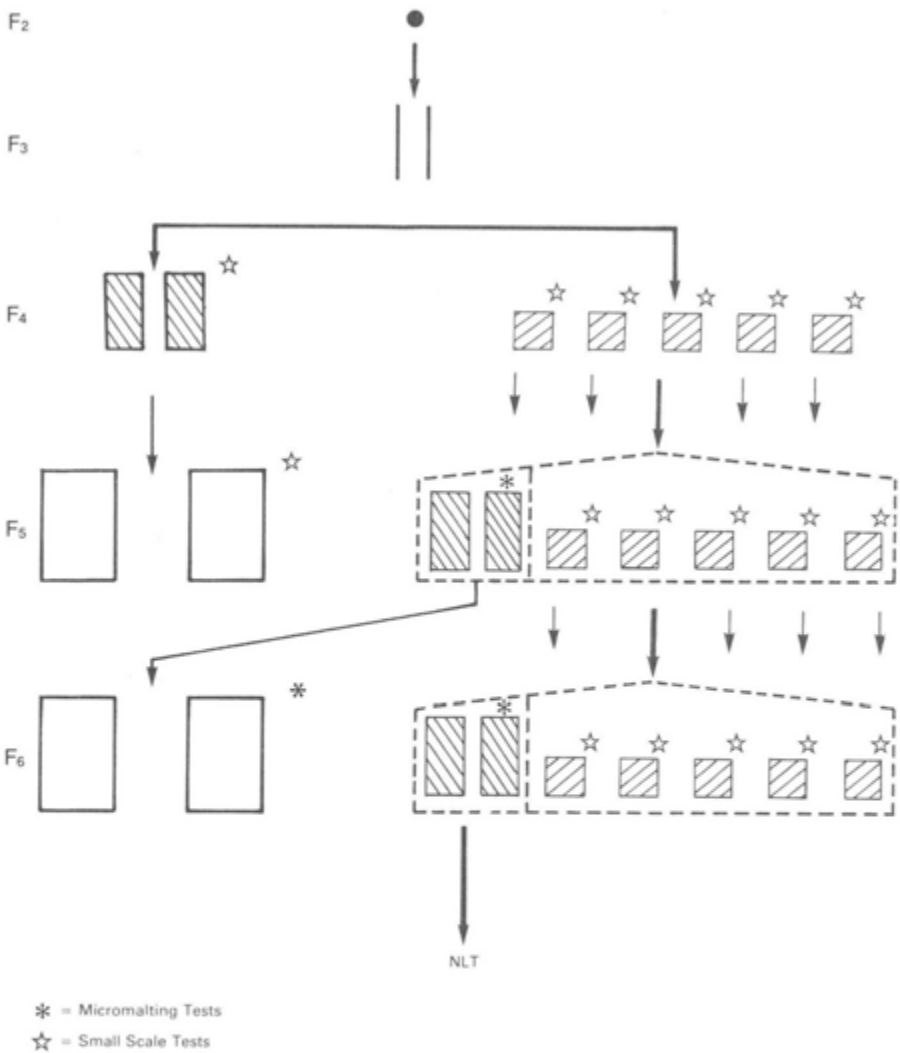

Figure 6. Current barley breeding scheme used by the S.P.B.S. Cereals Department.

- ● F_2 single plant selection
- II F_3 rows
- ▨ Small plot trials
- □ Large plot trials
- ▨ Progeny plot

An interesting comparison can be drawn between the problems encountered at the start of the high diastase and the malting quality programmes. In 1974 good malting quality was available in adapted two-row varieties while high DP was not. For example, the 1974 Recommended List of spring barleys, issued by the National Institute of Agricultural Botany, listed nine varieties (out of 17) approved as having malting potential by the Institute of Brewing. A closer inspection of these varieties however, indicated problems either with morphology or disease resistance. A new malting barley for Scotland would have to compete with Golden Promise which is acceptable to the maltster and also to the farmer because of its short, stiff straw, early ripening and resistance to head loss. None of the listed varieties listed in 1974 had straw as short and stiff as Golden Promise but Mazurka and Zephyr had reasonably strong straw. All of the varieties were later-maturing than Golden Promise, but with the exception of Maris Mink and Proctor, not seriously so. However, the wetter and windier conditions experienced in many Scottish harvest seasons make both Mazurka (prone to head loss) and Zephyr (prone to grain splitting) less acceptable than Golden Promise.

Golden Promise is notable also because it lacks major gene resistance to any of the commercially important foliar pathogens. Thus it seems desirable in this situation to promote dual, i.e. genetic and chemical, methods of combating diseases. In 1974 the NIAB listed varieties with reasonable malting quality were also disease susceptible. Mildew (*Erysiphe graminis*) was the most important of the foliar diseases and good levels of resistance were present only in Maris Mink, Mazurka and Wing. None of these varieties however had good resistance to all of the commercially important foliar diseases, namely yellow rust, brown rust or *Rhynchosporium*. Hassan with moderate mildew resistance had the best combination of rust resistances.

While it was possible to isolate a reasonable amount of variation for malting quality and morphological characteristics, disease resistance was much more problematical. Many sources of disease resistance have been identified (Torp *et al*, 1978; Wiberg, 1974; Macer and van den Driessche, 1966; Udeogalanya and Clifford, 1978). Often, new sources involve two-row by six-row crosses with the consequent physiological problems already encountered in the high diastase programme.

The lack of appropriate epidemics for the isolation and study of disease resistance has been a major problem in the SPBS cereal breeding programmes. Successful selection for mildew resistance can be carried out in most seasons under Scottish field conditions. *Rhynchosporium* and rust epidemics, however, need special nurseries inoculated with appropriate races. This has been attempted for *Rhynchosporium* since 1975 and for the rusts since 1976. There has also been considerable assistance from colleagues at WPBS who can screen advanced lines for *Rhynchosporium* susceptibility.

Many of the important components of malting quality are complex and their inheritance is not clearly understood. Sparrow (1970) has pointed out that characters affecting malting quality can be difficult to study because genetically controlled differences can be obscured by bio-chemical interactions.

The inter-relationships of malting quality components can be illustrated by reference to three equations that have been used to predict hot water extract (HWE) (Hough *et al*, 1971):—

$$HWE = A - 11{\cdot}0\ N_2 + 0{\cdot}22\ G$$
$$HWE = A_1 - 10{\cdot}0\ N_2 - 0{\cdot}3\ Z - 0{\cdot}2\ X$$
$$HWE = 138{\cdot}2 - 9{\cdot}5\ N_2 - 3{\cdot}0\ I$$

Where:

A and A_1 = varietal constants
N_2 = grain nitrogen per cent
G = thousand corn weight
$Z = G^{-1}$
X = per cent dead or dormant grain
I = per cent insoluble carbohydrate

The broad-sense heritability of grain nitrogen content has been found to be between 0·38 and 0·84 (Sparrow, 1970) and grain nitrogen estimates provide an estimate of environmental influence if the range of genetic variation is not too great. Thousand corn weight has been shown to have a narrow sense heritability of about 0·4 and a broad sense heritability of about 0·8 (Riggs and Hayter, 1975). The broad-sense heritability of hot water extract, which depends on grain composition, rate of germination and the resultant enzyme levels, has been shown to be between 0·43 and 0·69 (Sparrow, 1970). The biochemical and genetic basis of a dormancy and insoluble carbohydrate are not fully understood.

Whitehouse (1970a, 1970b) has suggested that the use of canonical analysis is appropriate for the choice of parents in such complex situations. This method reduces complex data to a form which can be more readily appreciated. Its application can be illustrated by data from a trial containing twenty varieties where thirteen field characters and eleven components of malting quality were measured. The analysis was only partially successful in reducing the dimensionality of the data as thirteen canonical variates showed significant chi^2 values. However, the first two canonical variates (Figure 7) accounted for 62 per cent of the total variation. The characters which contributed most to the discrimination of the varieties by these two canonical variates were the number of days to ear emergence, ear length and height (Table 23).

Genetic correlations between cold water extract and height were just significant ($r = -0{\cdot}5$, $P<0{\cdot}05$) but those between cold water extract and days to ear emergence and ear length were not. The significant correlation reflects

the varietal composition of the trial with older, taller varieties producing lower extracts. The absence of correlations between cold water extract and ear emergence and ear length indicates that it would be possible to select for either of the latter without affecting extract.

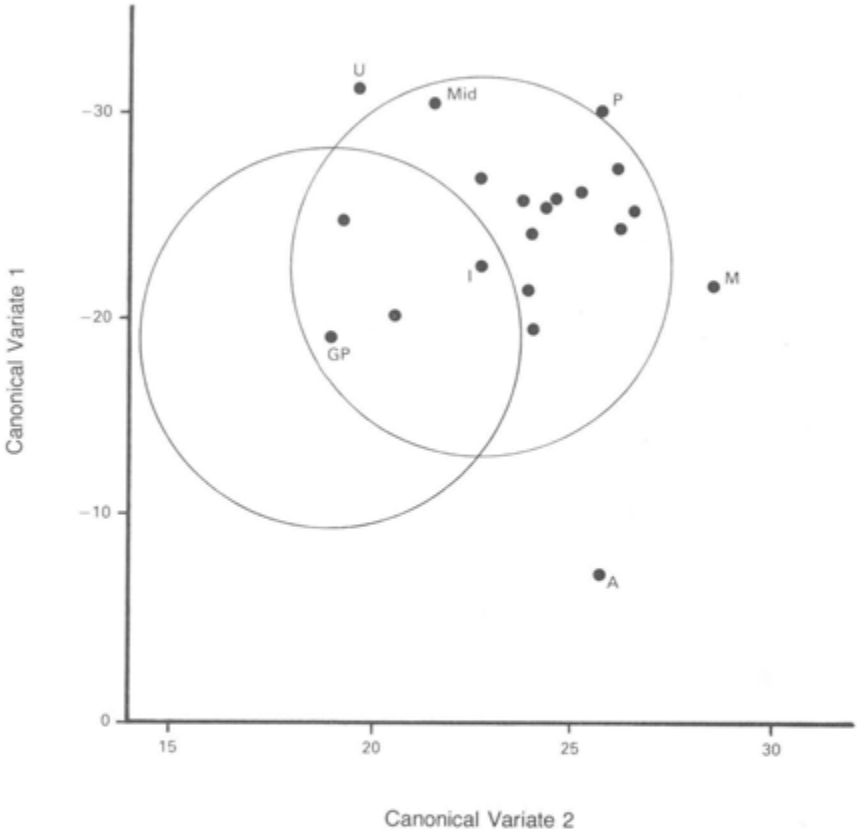

Figure 7. Canonical diagram for twenty varieties. The analysis included twenty-four field and malting quality characters. The first axis accounted for 47% of the total variation and the second for 16%. The circles represent 5% confidence limits based on Imber and Golden Promise.

A	Akka
GP	Golden Promise
I	Imber
M	Mazurka
Mid	Midas
P	Proctor
U	Universe

TABLE 23

Values for the first four canonical variates for six field characters and five components of malting quality.

Character	1	2	3	4
Height	0·4	2·1	0·2	0·2
Days to ear emergence	−3·1	0·9	0·9	−0·4
Ear length	−0·7	0·3	0·4	−1·1
Flag leaf length	0·0	0·1	0·8	0·0
Grain number per ear	0·3	0·0	−0·1	−0·8
Thousand corn weight	−0·1	0·2	−1·0	0·6
Waste (per cent)	−0·1	−0·5	−0·3	−0·6
Cold water extract	0·7	−0·1	0·6	0·1
Insoluble carbohydrate	0·6	−0·2	0·5	0·4
Weight after steep	0·4	0·9	0·1	−0·1
Predicted diastatic power	0·1	0·7	0·1	0·3

CROSSING FOR A PEDIGREE PROGRAMME

Parents which showed high levels of hot water extract were crossed with parents chosen as sources of disease resistance and good agronomic characteristics. Many simple pair-crosses were made but three and four parent crosses were also used. Three-parent crosses in which one of the parents was an unadapted variety have been difficult to deal with. Four parent crosses of the type, (adapted variety × disease resistance source) × (adapted variety × agronomic character source) have been easier to handle, but it is not yet certain that recombination would not have been more quickly achieved in a multiple series of pair-crosses with intermediate selection. This programme has been running for a comparatively short time (six years less than the high diastase programme from which we have noted above that the first NLT submission will be made in 1980), but should be in a position to make the first NLT entry at the end of 1980 or 1981. In contrast to high diastase breeding, the biochemical aspects of malting quality are concerned not only with the enzyme potential of the grain, but also with the starch granules, cell walls and general structure of the endosperm. Research on these topics has led to a better understanding of endosperm breakdown and to the development of small scale malting quality tests which can be applied in the early stages of the breeding programme.

Starch Composition

There has been a considerable research effect directed towards a clearer understanding of the composition, synthesis and degradation of starch. Many cereal starches consist of amylose and amylopectin in a one to three

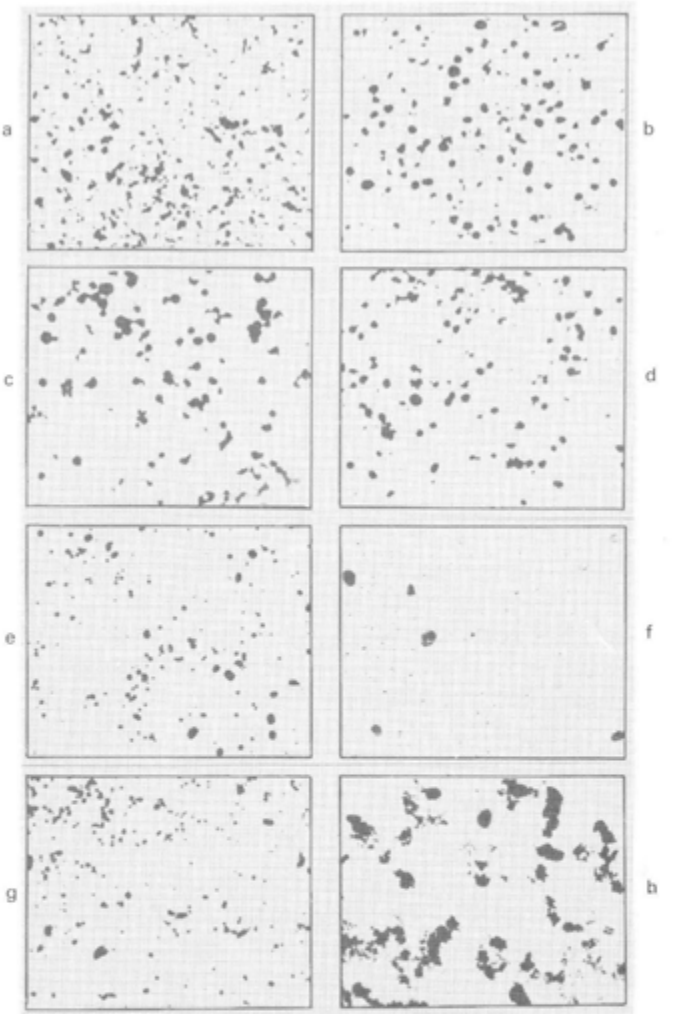

Figure 8. Some properties of high amylose starch illustrated by photomicrographs of granules mounted in iodine.

a High amylose starch granules (Glacier Ac 38 three dose endosperm).
b Glacier Ac 38 × Normal starch type (two dose endosperm).
c Normal starch type × Glacier Ac 38 (single dose endosperm).
d Normal starch type parent.
e High amylose starch separated from endosperm by toluene extraction was relatively resistant to digestion by a mixture of α- and β-amylase (Ellis, 1976).
f Normal amylose starch after the same treatment as *e*.
g Isolated high amylose starch granules after treatment in water at 65° for 1 hour. Relatively few granules have been disrupted.
h Isolated normal amylose starch granules after the same treatment as *g*. Most of the large granules have been disrupted but small granules are intact.

ratio (Deatherage *et al,* 1954). Both components are glucose polymers but amylose has a lower molecular weight and fewer branches than amylopectin. It has been suggested that a change in the relative amount of amylose might be beneficial. For example, Sandstedt *et al* (1968) proposed that waxy maize starch, with no amylose, was more readily digested by animals while Merritt (1969) and Pyke (1968) postulated that barley with a high amylose content would be more readily degraded during malting.

Merritt (1967) reported the discovery of a barley mutant, Glacier (Ac 38) in the collection held at the SPBS with higher (42 per cent) than the usual amount (28 per cent) of amylose in its starch. The high amylose line was shown to be otherwise isogenic with normal amylose Glacier (Ac 1191). Walker and Merritt (1969) demonstrated that in Glacier (Ac 38), high amylose was determined by a single Mendelian factor which was recessive to the allele determining normal amylose content. A back-crossing programme was started at SPBS to transfer the character into more adapted malting quality varieties such as Maris Druid, Proctor, Midas and Zephyr. The segregation of normal amylose and heterozygous lines was followed by scoring for starch granule type as suggested by Merritt and Walker (1969) (Figure 8).

A study of the development of starch in Glacier (Ac 38) and (Ac 1191) indicated that the increase in amylose was not at the expense of starch content (Merritt and Walker, 1969) while a chemical investigation revealed that high amylose starch granules gelatinised less readily than the normal type (Banks *et al,* 1971).

The sixth backcross to four of the recurrent parents was completed in 1970 (*Ann. Rep. 1970-71,* 21) but the amylose contents of the putative high amylose lines was not as high as expected. The segregation ratios found during the backcross programme were re-examined (Table 24) and found to be compatible with the single gene hypothesis. However, when the selfed

TABLE 24

Segregation ratios for starch granule type in backcross and selfed backcross lines. Segregants were classified as homozygous normal amylose (N), heterozygous (Ht) or homozygous high (H).

Backcross generation

	1	2	3	4	5	6
Class	N Ht	N Ht	N Ht	N Ht	N Ht	N Ht
Observed ratio	105:120	197:215	123:148	134:134	53:91	50:51
chi² 1:1	1·0	0·8	2·3	0·0	6·9**	0·1

Selfed backcross generation

	2	3	4	5	6
Class	N Ht H	N Ht H	N Ht H	N Ht H	N Ht H
Observed ratio	137:90:50	158:169:84	83:105:59	44:36:5	98:102:0
chi² 1:2:1	84·5***	39·6***	10·2***	37·8***	96·1***
chi² 13:3†	0·1	0·8	4·3*	9·2**	46·2***

*=$P<0.05$ **=$P<0.01$ ***=$P<0.001$

† based on the ratio (N+Ht):H

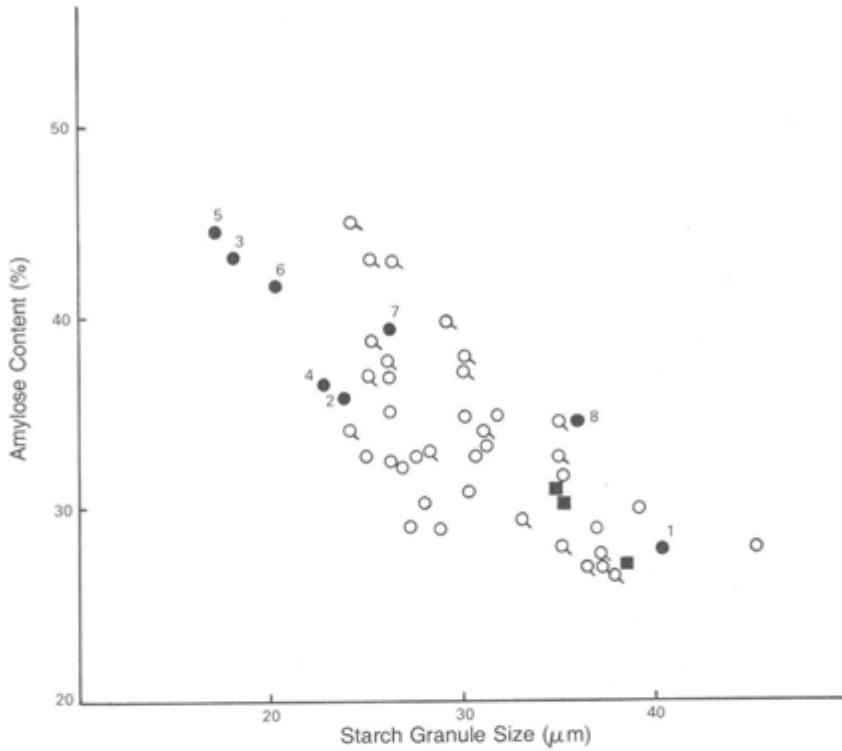

Figure 9. Correlation of amylose content and starch granule size. (r = −0·69***)

● = Glacier genotypes;

1. Glacier Ac 1191, normal amylose content.
2. Glacier Ac 38 sample 1
3. ,, ,, ,, 2
4. ,, ,, ,, 3 } high amylose content.
5. ,, ,, ,, 4
6. ,, ,, ,, 5
7. Glacier Ac 38 × Glacier Ac 1191 F1
8. Glacier Ac 1191 × Glacier Ac 38 F1

■ = Varieties with normal amylose content.

○ = Segregant from selfed backcross lines previously selected as being of normal amylose starch granule type.

Q = Segregant from selfed backcross lines previously selected as being of high amylose starch granule type.

generations were examined an excess of homozygous normal lines was found. The observed ratio was closer to 13:3 (normal homozygotes plus heterozygotes:high amylose heterozygotes) and the chi² summed over the generations containing high amylose types was not significant (chi² = 14·3, $P>0.05$), suggesting that more than one factor was involved.

At this stage it was decided to introduce a chemical assay for amylose content and eventually the Autoanalyser method of Robyt and Beamis (1967) was adopted. The correlation of amylose content with starch granule size was

re-examined using an estimate of maximum starch granule size rather than simple visual typing (Figure 9).

In a range of material a significant negative correlation was found between maximum starch granule size and amylose content ($r = -0{\cdot}69$, $P<0{\cdot}01$). It became apparent that amylose content in different samples of Glacier (Ac 38) varied over a wide range, with the lowest values being equivalent to that found in the F_1 Glacier (Ac 38) × Glacier (Ac 1191). In addition, lines previously selected as having the high amylose starch granule type had amylose contents ranging from normal to high levels.

TABLE 25

Amylose contents for lines derived from, by selfing, the third to sixth backcrosses to a series of normal amylose parents. Selection between S1 and S2 was for starch granule type, between S2 and S3 for maximum starch granule size, and between S3 and S4 by a chemical assay for amylose content. N = homozygous normal, H = homozygous high amylose as defined by Walker & Merritt (1969).

		Generation of Selfing			
		S1	S2	S3	S4
Backcross	*Genotype*				
Third	H	31·8	36·9	37·3	42·7
	N	29·3	30·4	32·2	29·7
Fourth	H	31·2	36·7	35·5	40·9
	N	29·3	31·0	30·9	29·0
Fifth	H	31·6	28·8		
	N	29·2	29·3		
Sixth	H	30·3	30·0	30·3	
	N	30·1	30·6	31·1	

When the selfed lines from the third to sixth backcrosses were assayed for amylose content (Table 25) it was found that the difference between putative homozygous high and normal lines in the first selfed generation (S1), selected on the basis of starch granule size, was not very large. Subsequent selection for starch granule characters increased the differentiation and allowed the recovery of high amylose genotypes in the second selfed generation (S2) of lines from the third and fourth backcrosses, but not the fifth and sixth. After three cycles of selfing and selection (S3) lines were reselected by scoring for amylose content as determined by the Autoanalyser method. High amylose S4 lines were obtained having similar composition and starch granule characteristics to Glacier (Ac 38). The S3 selections were used in a crossing programme with newer varieties such as Maris Mink, Universe and Midas and also with varieties which have a high α-amylase levels such as Maris Dingo.

Selected S4 lines were used to test the original hypothesis that high amylose starch would be more completely degraded during malting and fermentation. This could not be tested in Glacier (Ac 38) because, when grown in Scotland, this North American variety produced very slow germinating grain. For example, gibberellic acid treatment increased germination at five days from 50 to only 70 per cent (Ellis, 1976) while Zephyr showed complete germination. Glacier samples developed only half the α-amylase levels of the

Zephyr control. Glacier, grown in North America, has been malted (Pomeranz *et al*, 1972) and a relative reduction in the hot water extract of the high amylose mutant reported. When the isogenic S4 lines were malted this reduction in hot water extract in high amylose types was confirmed. The high amylose lines were also lower than the normal lines in α-amylase and this difference might affect the rate of modification, such that lines with lower α-amylase yield poorer extracts. However, isolated starch granules were used to demonstrate that high amylose granules were more resistant to both enzyme attack and gelatinisation, so the physical properties of the starch granules were also important (Ellis, 1976). In addition to research work on starch which is an α-glucan, considerable attention has also been paid to the β-glucans in the endosperm, particularly in relation to malting quality.

Small Scale Tests

β-GLUCAN

β-Glucan is a collective term for a group of substances containing glucose units, linked via β- 1,4 and β- 1,3 linkages, and which together constitute the principal component of barley endosperm cell walls. During malting, a rapid rise in the rate of β-glucanase production occurs usually after three to four days germination. (Bourne and Pierce, 1970). New malting methods with a short malting time, generate malts in which β-glucanase production has been stopped before maximum activity is reached, so the content of this enzyme in the wort is greatly decreased, resulting in higher β-glucan levels, as less hydrolysis has occurred. This problem is further compounded in breweries that use unmalted barley as an adjunct, since this is a source of β-glucan, but not of the enzymes which degrade it. Scott (1972a) showed that β-glucan was not only important in raising the viscosity of the wort, but it could survive fermentation and precipitate from beer during storage.

Interest in β-glucan as an undesirable feature in malting barleys has centred on two main areas; in β-glucan as a cell wall component, and therefore as a potential barrier to the movement of endosperm degrading enzymes during the malting process, and as the most significant of the barley gums responsible for limiting the rate of wort run-off from the mash tun during brewing. Direct measurement of soluble β-glucan which involves lengthy extraction processes, is impractical in a breeding programme because of the large number of lines generated, so rapid methods which measure β-glucan indirectly have been developed.

Greenberg and Whitmore (1974) estimated the viscosity of extracts of barley flour in an acid buffer. Their estimates related well to the β-glucan content as estimated by Bourne and Pierce (1970) and Greenberg (1974) postulated an equation which allowed percentage β-glucan to be calculated from extract viscosity measurements. It was also observed that these results correlated with the malting grades in the NIAB Recommended List of varieties so the test was used to assess malting potential of breeding lines.

Morgan and Gothard (1977) modified this method and reduced the sample size required such that a single ear provides sufficient sample. They also showed that a one hour extraction period, rather than the original four hours, did not significantly reduce the correlation with malting grade ($r = -0{\cdot}72$ after four hours, compared to $r = -0{\cdot}68$ after one hour).

Morgan (1977) plotted extract viscosity against time over a one to six hour period. He observed that there was a drop in viscosity between three and four hours for varieties of good malting quality, whereas viscosity continued to increase over this period when varieties of poor quality were tested. He postulated a dynamic balance between viscosity enhancing and viscosity reducing factors, the former depending on the quality and nature of the β-glucan extracted, whereas the latter could be due to an acid hydrolysis resulting in shorter β-glucan chains of lower viscosity. As the change in viscosity which occurs between three and four hours extraction correlated with percentage extract after micro-malting, ($r = +0{\cdot}81$, d.f. = 39) he advocated the measurement of this viscosity difference as a test for predicting malting quality.

INFRA-RED REFLECTANCE

The nitrogen content of the grain also plays a role in determining malting quality, as potential extract from the grain usually decreases as nitrogen increases. This is probably due to incorporation of nitrogen into protein which occupies some of the endosperm space normally available for starch deposition. In addition the quantity of extract is also limited by the restriction of access of malt hydrolases to starch by the proteinaceous matrix in which the starch granules are embedded.

These considerations emphasise the need to take β-glucan and nitrogen into account in any assessment of malting quality. Manual analytical procedures for the estimation of these two barley constituents are both lengthy and labour-intensive. Allison *et al* (1978), therefore, adopted a new means of measuring nitrogen and the technique was extended so that β-glucan could be measured simultaneously on the same sample. This was achieved using an infra-red reflectance instrument called the InfraAlyzer (made by Technicon, Ltd.). This machine is marketed for the estimation of crude protein, oil and moisture in cereals. It measures the energy reflected at six fixed wavelengths in the near infra-red spectrum. If one of these wavelengths is near the absorption peak of a particular compound, then absorption or reflectance at that wavelength is related to the concentration of that component in the sample. A second wavelength acts as a reference as the amount of energy reflected at the reference wavelength is constant regardless of changes in concentration. There are three pairs of wavelengths (one pair for each of oil, protein and moisture in cereals) used in the InfraAlyzer. A number of samples (over 30) covering the usual range of concentrations encountered during an analysis, are scanned by the InfraAlyzer. From these samples the reflected energies at the six wavelengths enable a multiple regression to be constructed using the equation:—

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$$\% \text{ concentration} = K_1 \log_1 + K_2 \log_2 + K_3 \log_3 + K_4 \log_4 + K_5 \log_5 + K_6 \log_6 + K_0$$

where $\log_1$ = the logarithm of the reflectance energy at wave-length 1 and K_0 — K_6 are constants (a separate set of constants for each of the three components) derived by measuring the reflective energies, at each of six wavelengths, for samples of known concentration. The relationship between predicted values and manually estimated values for β-glucan are shown in Figure 10.

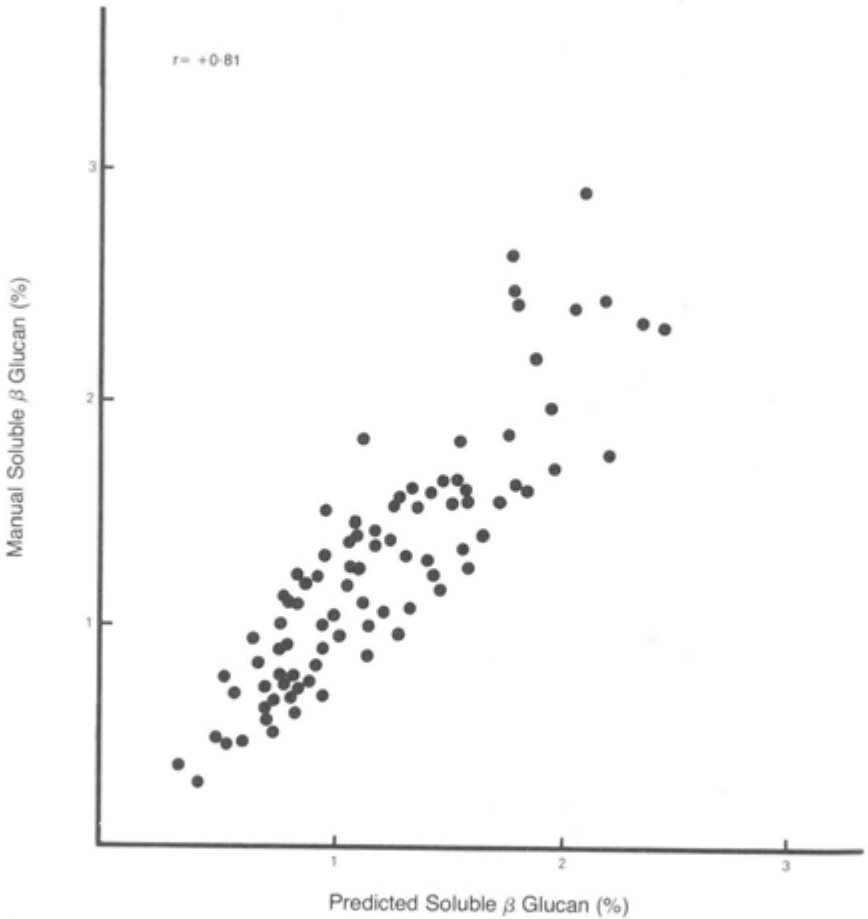

Figure 10. Manually estimated values of soluble β-glucan plotted against InfraAlyser predicted values.

Samples were scanned in the InfraAlyzer for the prediction of β-glucan. An equation with constant values of, $K_0 = -5{\cdot}19379$, $K_1 = -0{\cdot}00210$, $K_2 = 0{\cdot}04567$, $K_3 = -0{\cdot}00213$, $K_4 = -0{\cdot}04567$, $K_5 = 0{\cdot}00839$, $K_6 = -0{\cdot}02306$ gave predicted β-glucan values that correlated with the manual results ($r = +0{\cdot}807$

$P<0{\cdot}001$). In these experiments Ark Royal had a very low β-glucan content, below 0·6 per cent, whereas Lami had a high content, greater than two per cent β-glucan. The relationship between estimated and predicted β-glucan is fan-shaped (Figure 10) and the poorer prediction at higher values may be due either to different β-glucans of higher molecular weight or to pentosans being brought into solution when varieties of poor malting quality are extracted. The InfraAlyzer was calibrated for the simultaneous prediction of nitrogen (Figure 11) and moisture in addition to β-glucan, on the same sample. The system is therefore potentially useful when screening for these attributes of malting quality, and requires a sample of only five grams.

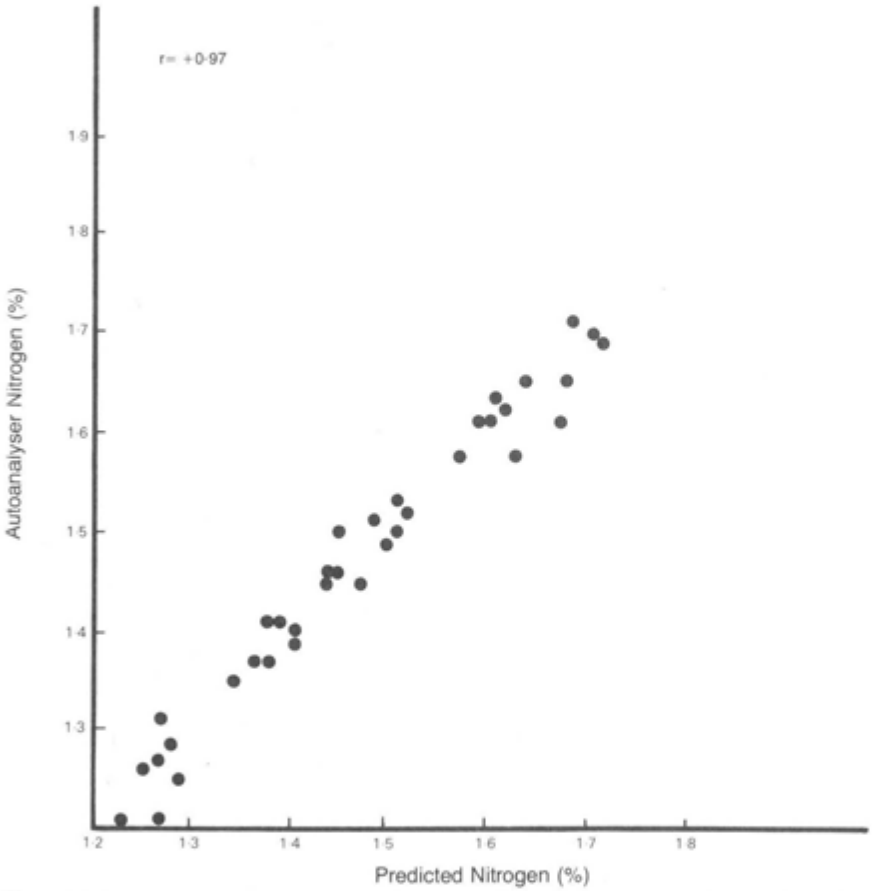

Figure 11. Estimates of nitrogen made on the Autoanalyser plotted against values predicted by the InfraAlyzer.

SEDIMENTATION TEST

During investigations of the endosperm structure of different varieties it was observed that coarsely-milled endosperm fractions of Maris Otter always left a greater number of starch granules in suspension in 70% ethanol

than similarly milled fractions of Julia. Palmer (1975) showed that this result could be readily reproduced by using a controlled milling and sieving regime. Samples of unmalted barleys are milled in a Moulinex coffee mill, in which the blades have been blunted, and that portion of the resultant flour which can pass through a 250 μm mesh sieve is collected and a small quantity is shaken with 70% ethanol. After allowing eight minutes for sedimentation to occur, the relative densities of the supernatants are read off a nephelometer. Subsequently we were able to eliminate sieving by the use of a Udy cyclone mill to grind samples. This allows a sample which has been milled for InfraAlyzer analysis to be used for the sedimentation test.

When this test was applied to other barley varieties, it was found that lower densities, and therefore more rapid sedimentation, were usually associated with varieties of poor malting quality and variations in sedimentation rates were attributable to the physical and chemical nature of the endosperm cell wall and the starch-protein matrix. Some differences were observed within varieties and between seasons, but this did not appear to be linked to differences in grain nitrogen content. It was also noted that a few barleys, regarded to be of reasonably good malting quality, performed less well than would be expected, but since the test is based on endosperm characters which probably facilitate modification, it may well select the faster malting varieties rather than give an accurate indication of malting potential.

When a sample of barley is dehusked with 50% sulphuric acid, grains can be separated, on the basis of external appearance, into mealy, vitreous and intermediate groups. Recent work, described in the Brewing Research Foundation's Annual Report for 1977 indicates that mealy grains sediment most slowly and modify most rapidly. Furthermore, when grains of varieties which perform well in the sedimentation test are observed under the microscope, a greater proportion are shown to have an endosperm with a crumb-like structure than is found in other varieties. Vitreous grains may contain discrete areas of mealiness, with more of these areas being associated with varieties such as Proctor which has the slow sedimentation rate of a variety with malting potential.

MILLING TESTS

A small scale milling energy test developed at SPBS measures grain hardness in relation to potential malting quality (Allison *et al*, 1976). The apparatus first used was a modification of that devised by Chenost (1966) to measure the fibre content of grass. His original apparatus consisted of a Glencreston micro-hammer-mill connected via a transducer to a chart recorder. With only minor changes to this system it is possible to estimate barley grain hardness. When grains enter the mill chamber from the hopper, with the mill running, the resulting load on the motor is traced on a pen-recorder as a steeply increasing voltage followed by a slower return of the trace to the base-line, as all the grain is pulverised to a flour capable of passing a one mm

sieve. The whole trace is completed in about thirty seconds. Milling energy values for a trial of twelve varieties ranked them in order of their malting grades according to the NIAB Recommended List. One variety, Mazurka fitted the correlation less well (Figure 12). The results indicate that this rapid milling test measures an attribute of the endosperm that relates to malting quality.

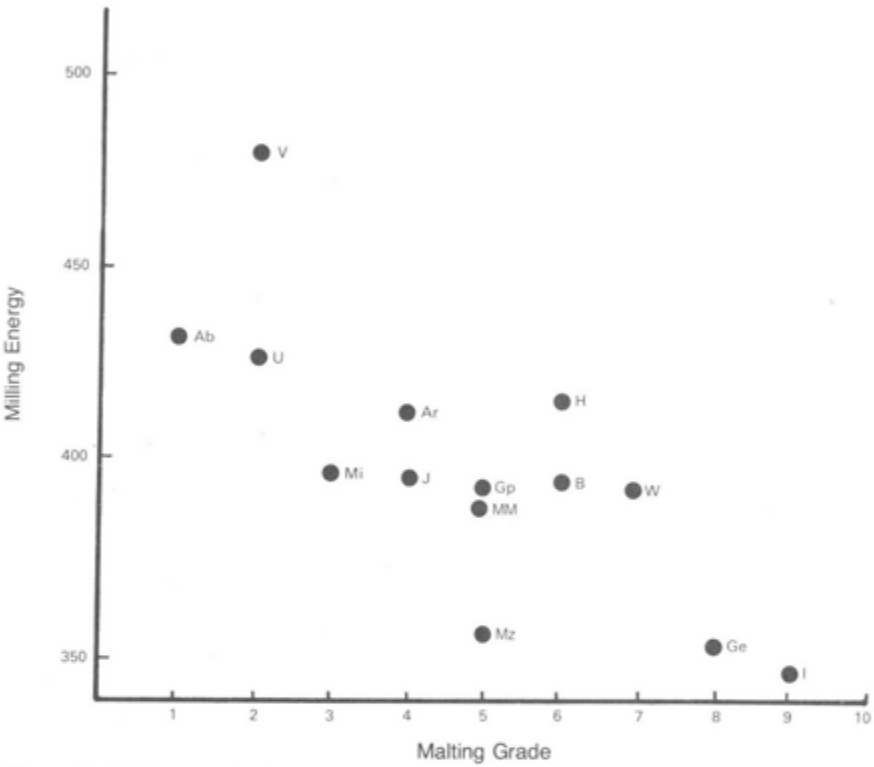

Figure 12. Milling energy plotted against malting grades of barley given by the NIAB list of recommended varieties.
Ab = Abacus, Ar = Armelle, B = Berac, Ge = Gerkra, GP = Golden Promise, H = Hassan, I = Imber, J = Julia, MM = Maris Mink, Mi = Midas, Mz = Mazurka, U = Universe, V = Vada, W = Wing.

Intensive usage of this original apparatus, however, resulted in problems of mill wear and a consequent loss of repeatability of the measurements. Together with the need to automate some of the procedures this led to the development of a different method of measuring the energy required to mill a sample. A new milling apparatus based on a flywheel system was developed at SPBS in collaboration with Calan Electronics Ltd. and several processes including the release of the sample into the mill chamber, were automated. One important consequence of these modifications is an improvement in the repeatability of milling energy measurements. The new mill, called a "Comparamill", uses the kinetic energy of a rotating flywheel to drive the mill

hammers in a modified Glencreston mill. The energy lost as the fly-wheel decelerates during milling is given by the equation:—

$$KE = 1(W_1^2 - W_2^2) / 2g$$

where KE is the kinetic energy loss in joules
I is the inertial constant of the flywheel
g is the gravitational constant
W_1 is the initial speed of the flywheel in radians per second
W_2 is the final speed of the flywheel in radians per second.
A prototype "Comparamill" is shown diagrammatically in Figure 13. It consists of a mill connected to a flywheel with an associated control unit. Milling operations are controlled by a micro-processor which monitors the sequence of operations and calculates the results.

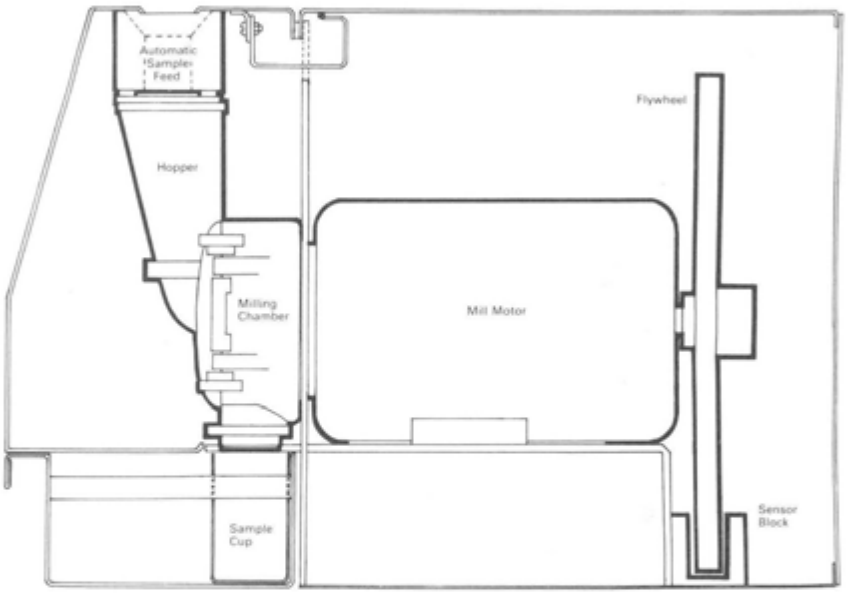

Figure 13. A diagrammatic representation of the flywheel mill used in the "Comparamill" system.

Before any series of measurements is made the "Comparamill" is calibrated by running the system without a sample and subtracting the energy loss automatically for each subsequent milling. Calibration energies can be used to monitor wear and so far have shown that calibration results are highly repeatable. As "Comparamills" will have the same inertial constant and error due to wear is removed by the calibration procedure, results from different units should be comparable. Once the flywheel has been accelerated its speed is not allowed to fall below 3000 rpm. This ensures that the milling time of two to five gram samples (usually two seconds) is kept to a minimum. In practice one sample per minute is the average throughput.

Milling energy values (means of three measurements) from a "Comparamill" analysis of current varieties grown in single plots are plotted against hot water extracts of micromalted samples (60g samples) in Figure 14. Again with the exception of some samples of Mazurka there is a good correlation ($r = -0{\cdot}76$, $P<0{\cdot}01$) between milling energy and extract value. If the Mazurka samples are included the correlation becomes $r = -0{\cdot}59$, $P<0{\cdot}01$. Further investigation has shown that the three Mazurka samples which do not fit the general regression, were part of a trial grown at Pentlandfield. All three samples had low α-amylase activity, whereas a Mazurka

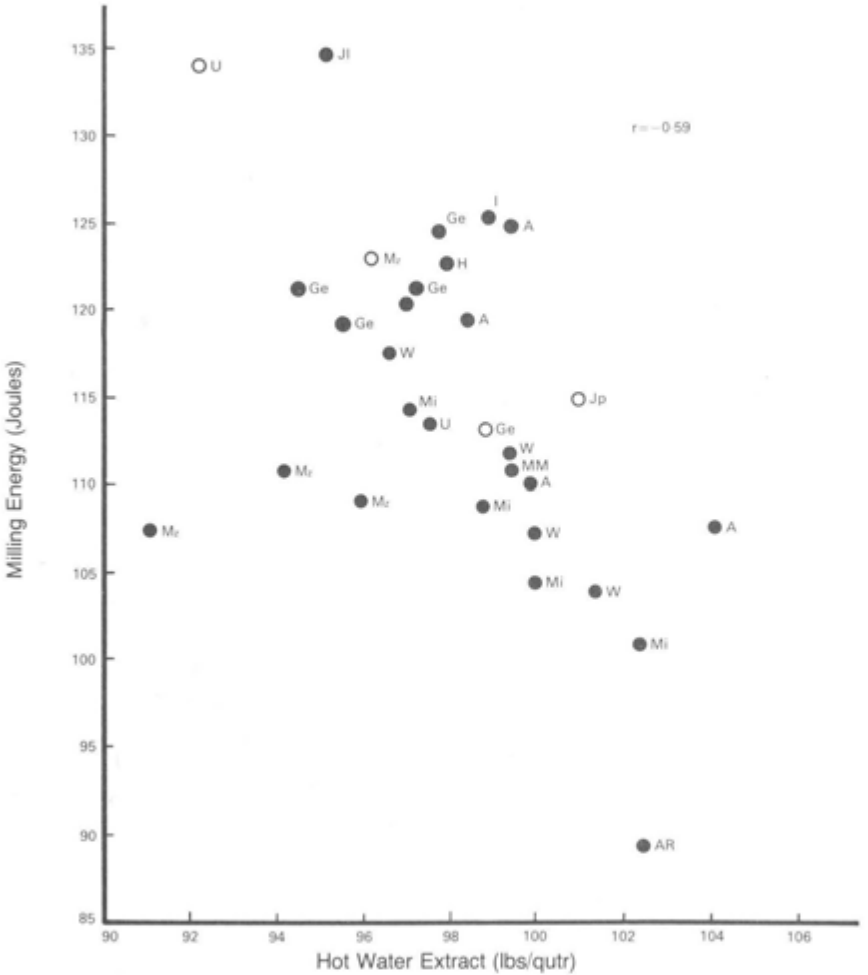

Figure 14. Milling Energy plotted against hot water extracts of micromalted samples of A = Abacus, AR = Ark Royal, Ge = Gerkra, H = Hassan, I = Imber, Jl = Julia, Jp = Jupiter, MM = Maris Mink, Mi = Midas, Mz = Mazurka, U = Universe, W = Wing.
● — Grown at Pentlandfield.
○ — Grown at the Murrays.

sample grown at the "Murrays" with a level of α-amylase typical of current varieties, did fall on the regression line (see Figure 14). Thus a barley variety may have a relatively "soft" endosperm which can potentially modify quickly but is still restricted in malting rate by poor production of hydrolysing enzymes.

Samples of a number of varieties (including Imber, Gerkra, Abacus and Jupiter) did not malt as might be expected from their malting grades given by NIAB. However, in previous trials grown at the Murrays, Imber and Gerka gave high extracts. That there is a strong effect of the environment on milling energy and malting performance is supported by the range of results obtained for samples of Wing and Midas in Figure 14. High grain nitrogen values ($>$ 1·7%) recorded for Imber are, at least in part, responsible for the poor extracts obtained from both Imber samples.

A final version of the "Comparamill" will soon be available commercially and this will be marketed for rapid, highly repeatable measurements of the hardness of cereal grains and possibly other materials. An artist's impression of the "Comparamill" and its associated apparatus is shown in Figure 15.

Interest in grain hardness of cereals has not been confined to malting quality barleys, since the hardness of wheat grains influences the quality and potential use of the flour produced from them. To test this, a procedure called grinding resistance similar to the milling energy test has been developed (Stenvert, 1974). The grinding resistance test uses a micro-hammer mill, but instead of measuring the energy required to mill a sample, the time for a set quantity of flour to be delivered is recorded.

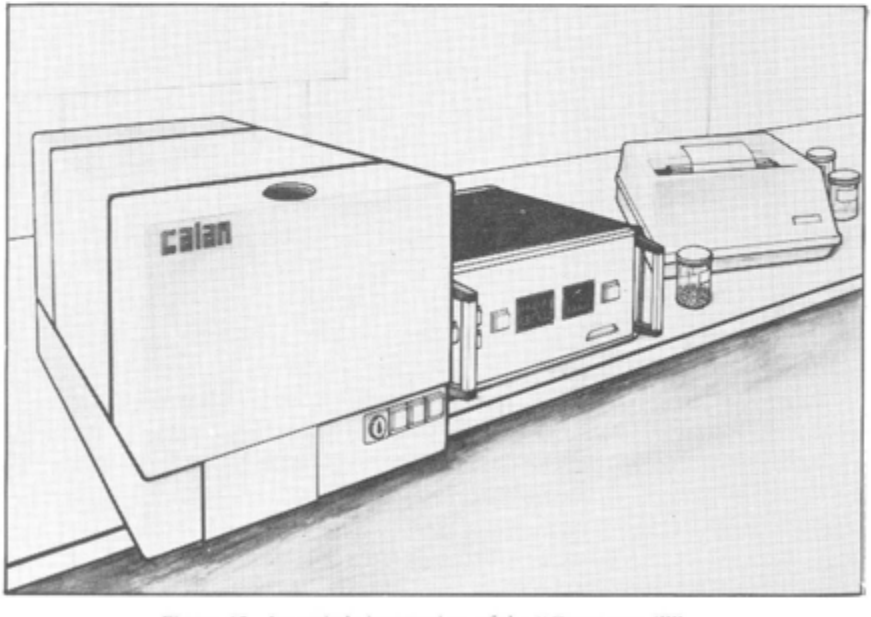

Figure 15. An artist's impression of the "Comparamill".

When this test was applied to barley grains, grinding resistance correlated with malting quality (Ellis *et al*, 1979). This test does, however, require a fairly large sample (20g) to give repeatable results and the milling energy test, while more expensive to set up initially, does have the advantages of being faster and requiring considerably less grain per sample.

A total of 480 cultivars from the museum collection at SPBS was screened for β-glucan content and the amount of energy required to mill them (Allison *et al*, 1979). Of these only nine cultivars had lower β-glucan and milling energy than Gerkra, a barley which usually malts well to give a high extract (Figure 16). The fact that there were few varieties with lower milling energy than Gerkra compared to the relative distribution of β-glucan contents, may indicate that selection for "softer" endosperms has occurred when barleys that modify readily were selected in those breeding programmes that included malting quality among the objectives.

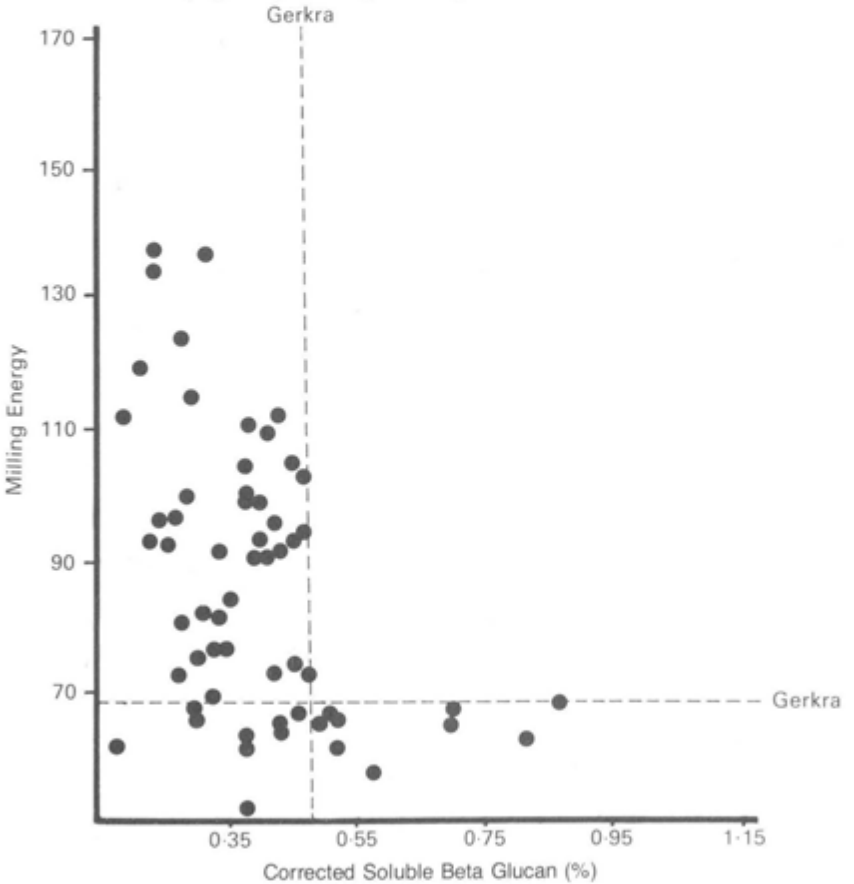

Figure 16. Milling energy plotted against soluble β-glucan for barley cultivars from a museum collection. For the sake of clarity all the cultivars with values higher than those of Gerkra, indicated by the dotted line, have been omitted.

Future Trends

Palmer (1975) outlined the major developments which have occurred in malting methods over the previous 25 years. In order to increase throughput in modern malting plants, a malting barley must yield a high extract in a short malting time. Consequently, recent developments in malting methods, such as addition of gibberellins or the use of abrasion, tend to be concerned with a speeding up of germination and enzymic modification of the endosperm.

The high yields of many current barley varieties make the growing of such varieties attractive to the farmer. Many of these varieties, however, may be excellent for animal feed, but are of poor malting quality. It is therefore evident that maltsters may have to learn how to apply processing methods to such barleys to enable a uniform germination and rapid modification of the endosperm. The rate of endosperm modification could be increased by breeding barleys with an endosperm structure which facilitates migration of hydrolytic enzymes during malting (Allison *et al*, 1979).

This is also the view of Wilten (1977) who suggested that farmers will continue to grow the highest yielding varieties, unless the prices obtained for malting barley make it a more attractive prospect. Possibilities do exist in the malting and brewing processes to correct the inadequacies of the barleys used, but a high yielding variety, which also malts readily, would be desirable. It is not difficult to explain the success of the variety Golden Promise in Scotland in recent years since it combines factors which appeal to both the farmer and the maltster, and it seems that future successful varieties, may need to be of this dual-purpose type.

A similar conclusion was reached by Gothard *et al* (1978) when the malting performances of a number of old and present day varieties were compared. Their results indicate that not only is there little evidence of improvement in malting ability between Plumage Archer and Ark Royal, but there seems limited scope for further increases in potential hot water extract. In the breeding of varieties, emphasis should be given to combining good agronomic characteristics with the ability to modify rapidly, without the need for abrasion and exogenous gibberellins. Problems in using high concentrations of gibberellins, to achieve accelerated malting, include a tendency to over-modification and dark colouration of the malt. However, a rapid development of α-amylase is unlikely without additional gibberellic acid (Home and Links, 1977) and a low level of amylolytic activity may limit the conversion of carbohydrate to simpler sugars during mashing and thus decrease the extract value. The choice of a suitable variety for malting is therefore very important.

There is, undoubtedly, a need for a closer understanding of the components of malting quality and their relative importance, particularly in view of recent developments in malting technology. There is a need to study the genetics of these characteristics. One particular area of research is outlined by MacLeod (1977). The means by which β-glucan of high molecular weight is

bonded in the cell wall is not yet understood and there is no generally accepted method available for estimating the amount of soluble, potentially viscous, β-glucan present at various stages of malting or for predicting the degradation pattern of barley cell wall components as the grain germinates. There is a need, therefore, to carry out further studies of β-glucan metabolism and to encourage the breeding of barley varieties of low total β-glucan content.

β-Glucan has assumed more importance due to the recent accelerated malting procedures which are stopped before sufficient levels of β-glucanases are produced (Bourne and Pierce, 1970). This is thought to be a problem, particularly where additional sources of β-glucan, in the form of unmalted barley, are added to the mash. The relationship between extract viscosity and malting grade (Greenberg and Whitmore, 1974), also indicates that a low level of β-glucan is a very important component of a malting barley and the development of infra-red reflectance techniques (Allison *et al*, 1978) has meant that β-glucan levels can be measured very rapidly, simultaneously with grain nitrogen content, at a rate of one sample per minute.

There is disagreement, however, regarding the importance of β-glucan, both as a guide to malting quality and in its effect on the rate of run-off from the mash tun. Ellis *et al* (1979) show that, over a wide range of genetic backgrounds the correlation between extract viscosity and hot water extract is not significant. In addition, the Brewing Research Foundation's Annual Report for 1977 describes a hydrazinolysis procedure for measuring the total β-glucan content of endosperm cell walls, or whole barley grains, and states that there is little correlation between total β-glucan content and malting behaviour. Schur and Pfenninger (1978) suggest that β-glucan is a relatively minor component, quantitatively, amongst high molecular weight materials in the wort and that its importance in filtration difficulties has been exaggerated. It is therefore possible that β-glucan is not such an important component as was previously thought, but both breeders and maltsters will probably continue to avoid varieties containing or producing very high levels.

Since the ability to modify rapidly has been stressed as an important feature of future malting barleys, (Palmer, 1975; Gothard *et al*, 1978) interest will continue to centre on the enzyme systems which degrade the endosperm, the structure of the endosperm itself and the ways in which endosperm components act as barriers to the enzymes.

The changes in malting methods have, inevitably, caused problems with regard to laboratory assessment of malting quality. Many of the standard methods have not changed for some years and originated at a time when similar prolonged malting methods were applied by maltsters to only a few varieties of barley. It is unrealistic to expect to find any single method which can assess all aspects of malt quality (Bourne *et al*, 1977). A similar situation exists for rapid, small-scale prediction tests on unmalted grain (Ellis *et al*, 1979) but comparisons of new, or modified established methods, have produced useful information for assessing both malted and unmalted barley

samples. For example, Bourne *et al* (1977) have examined a number of new methods of malt analysis and conclude that these give a much more complete picture than the present routine analyses, as far as extract and mash tun performance are concerned. They are useful not only in ensuring maintenance of quality when malting conditions are changed, but also in identifying defects in malts which cause problems in brewing.

For the breeder who wishes to screen large numbers of lines in early generations, rapid small-scale tests have been developed which can be applied to unmalted samples. A series of these has been compared (Ellis *et al*, 1979) to assess which combination of tests gave the most accurate prediction of hot water extract. The importance of α-amylase and milling tests which measure the hardness of the grain (Stenvert, 1974; Allison *et al*, 1976) was noted. As grain hardness probably relates to factors in the endosperm, such tests are likely to be much used in view of the importance of endosperm structure in malts produced by modern accelerated methods, but it also appears that there may well be an increasing number and diversity of tests in the future.

Much of what has been said about future trends in the breeding of malting quality barleys is also applicable to the high diastase breeding. Since the demand for this type of barley would be less than for conventional malting quality types, which are required for both the beer and whisky industries, farmers may require the offer of a premium as an incentive to grow them. The possibility of alternative purposes such as high yielding, animal feed varieties or some conventional malting potential might make them more attractive.

In conclusion, it seems that future research will be aimed at an increased understanding of the complex changes which occur during malting. Breeders will attempt to produce varieties which combine good agronomic qualities with components which enhance malting potential.

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VARIETIES BRED BY THE STATION

The following are commercially available in Britain:

Stubble-turnip
Appin

Horticultural kale
Pentland Brig

Potatoes
Craigs Alliance†
Craigs Royal
Red Craigs Royal†
Pentland Beauty
Pentland Crown†
Pentland Dell†
Pentland Hawk*
Pentland Ivory*†
Pentland Javelin*†
Pentland Lustre*
Pentland Marble*
Pentland Meteor*
Pentland Raven*
Pentland Squire*†
Croft*
Strath*

Varieties marked * have been granted Plant Breeder's Rights and licences to reproduce and sell stocks have been issued. The rights are held jointly by the Society and the National Seed Development Organisation and applications for licences should be made to the Executive Officer, NSDO Ltd., Newton Hall, Newton, Cambridge. The commercial development of Pentland Brig, which is a garden variety producing succulent leafy young shoots in early spring, is also in the hands of NSDO. Varieties marked † are on the NIAB Recommended List.

The following, recently named, were undergoing final trials or multiplications during the period covered by this Report:

Oats Etive* Fyne Leven*

PUBLICATIONS

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LIST OF PROJECTS

The work described in this Annual Report has been commissioned by DAFS under the following package numbers. (ARC project numbers are also shown).

DAFS Package	*ARC Project*	
1		**To provide improved cereal varieties suitable for production and utilization in Northern Britain**
	04001	Collect, assess and maintain oat and barley genotypes of use to breeders. Use computer-based data systems.
	04002	Survey physiological characters related to crop performance in barley and oats and construct breeding models.
	04003	Study inheritance of cereal performance characters. Design procedures to maximise and exploit variability.
	04004	Evaluate techniques for choosing parents and selecting offspring. Design data handling system for breeders.
	04005	Test cereals locally from this and other institutes. Explore potential of unfamiliar crops.
	04006	Survey virulence genes in pathogenes of oats and barley. Design strategies for disease resistance breeding.
	04007	Study mechanisms of partial resistance of oats and barley to *Erysiphe* and their use in resistance breeding.
	04008	Improve methods to establish oat and barley disease nurseries. Assemble virulence genes of main pathogenes.
	04009	Study biochemical components of barley and oat grains related to malting, feeding and processing quality.
	04010	Develop and automate small-scale tests for malting, distilling, brewing and milling quality.

DAFS Package	*ARC Project*	
	04011	Study enzymic hormonal and other biochemical factors affecting cereal development performance and yield.
	04012	Investigate inheritance of biochemical components of significance in breeding oats and barley.
	04013	Breed malting and feed barley cultivars.
	04014	Breed spring oat cultivars.
	04015	Produce pure seed stocks of new cultivars. Investigate diagnostic features of oats and barley.
	06001	Study of trial designs and field management for plant breeding.
4		**To provide improved varieties of swedes and forage brassicas for livestock feeding**
	03001	Exploit interspecific and intergeneric crosses as sources of variation for brassica and radicole breeding.
	03002	Develop and apply screening tests for useful and harmful biochemical components in brassicas and related spp.
	03003	Collect, assess and maintain genetic material of use to brassica breeders.
	03004	Agronomic, physiological, biochemical and genetic investigations to formulate brassica breeding objectives.
	03005	Identify and maintain S-alleles in brassicas. Study their strength and dominance relations.
	03006	Survey virulence genes in pathogens of brassicas. Design and initiate strategies for resistance breeding.
	03007	Improve methods for assessing brassica diseases and for estimating yield losses caused by them.
	03008	Assemble and test genetic sources of resistance to diseases of brassicas. Produce improved parents.
	03009	Breed F_1 hybrid and inbred swede cultivars.
	03010	Breed rape cultivars from natural and artificial genotypes of *Brassica napus* and related species.

DAFS Package	*ARC Project*	
	03011	Breed kale and fodder cabbage cultivars.
	03012	Breed turnip cultivars especially for Scottish uplands.
	03013	Breed brassica and radish catch crops for late sowing and autumn grazing. Breed fodder radish cultivars.
	03014	Breed radicole cultivars as substitutes for rape from hybrids of *Raphanus* and *Brassica*.
	03015	Test and multiply brassica radish and radicole cultivars.
7		**Potato breeding and related pathological and genetical studies**
	05001	Breed maincrop potato cultivars for quality, disease resistance and yield for fresh use and for processing.
	05002	Breed early potato cultivars for early yield and quality in relation to fresh use, crisping and canning.
	05003	Maintain and multiply healthy breeding and experimental stocks. Develop and apply improved health control procedures.
	05004	Screen breeding material for cooking and processing quality. Develop and use improved screening techniques.
	05005	Evaluate advanced potato selections in field trials in Scotland, England and Wales.
	05006	Study biometrical genetics of potato characters and devise improved breeding schemes.
	05007	Research into design and predictive efficiency of potato field trials and into G × E interactions.
	05008	Evaluate potato selection procedures and devise improvements for application in breeding programme.
	05009	Establish and manage computerised data bank on clones under selection in potato breeding programme.
	05010	Study biology of potato cyst eelworm including host parasite relationships and the nature of resistance.

DAFS Package	*ARC Project*	
	05011	Assess potato breeding material for resistance to potato cyst eelworm. Improve screening techniques.
	05012	Assess potato breeding material for resistance to and infection with viruses X, Y and leafroll.
	05013	Assess potato breeding material for resistance to soil-borne viruses. Improve screening techniques.
	05014	Study the biology of common scab, gangrene, skin spot and dry rot.
	05015	Assess potato breeding material for resistance to fungal diseases. Improve screening techniques.
	05028	Study mechanisms of genetic variability in *Phytophthora infestans* and the evolution of new pathogenic types.
	05029	Study mechanisms of quantitative resistance to potato late blight and identify resistant parental material.
8		**Commonwealth Potato Collection and related genetic/breeding studies**
	05016	Manage the Commonwealth Potato Collection of Latin American origin. Liaise with the Dutch/German gene bank.
	05017	Breed Neo-Tuberosum potatoes from Andigena origin for use in breeding cultivars.
	05018	Evaluate Neo-Tuberosum potatoes as parental material for use in breeding cultivars.
	05019	Breed diploid potatoes and evaluate as potential parents for diploid and tetraploid cultivars.
	05020	Produce, breed and maintain collection of dihaploid potatoes. Use dihaploids to enhance disease resistance.
9		**New Crops**
	06002	Studies of the contribution which plant breeding may make to the development of crops new to Scotland.

INSTITUTES FOR AGRICULTURAL RESEARCH IN GREAT BRITAIN

The research programmes of all the research Institutes supported from public funds are co-ordinated by the Agricultural Research Council. The following is a list of Institutes. Most of them publish reports annually and details can be obtained from the Secretaries of the Institutes concerned.

ARC Institutes:

* Animal Breeding Research Organisation	King's Buildings, West Mains Road, Edinburgh EH9 3JQ
Institute of Animal Physiology	Babraham, Cambridge CB2 4AT
Institute for Research on Animal Diseases	Compton, Newbury, Berks. RG16 0NN
* Food Research Institute	Colney Lane, Norwich NOR 70F
Letcombe Laboratory	Letcombe Regis, Wantage, Berks. OX12 9JT
Meat Research Institute	Langford, Bristol BS18 7DY
* Poultry Research Centre	King's Buildings, West Mains Road, Edinburgh EH9 3JS
Weed Research Organisation	Begbroke Hill, Sandy Lane, Yarnton, Oxford OX5 1PF

State-aided Institutes in England and Wales:

Animal Virus Research Institute	Pirbright, Woking, Surrey GU24 0NF
* East Malling Research Station	East Malling, Maidstone, Kent ME19 6BJ
Glasshouse Crops Research Institute	Worthing Road, Rustington, Littlehampton, Sussex BN16 3PU
* Grassland Research Institute	Hurley, Maidenhead, Berks. SL6 5LR
Houghton Poultry Research Station	Houghton, Huntingdon PE17 2DA
* John Innes Institute	Colney Lane, Norwich NOR 70F
Long Ashton Research Station	Long Ashton, Bristol BS18 9AF
National Institute of Agricultural Engineering	Wrest Park, Silsoe, Beds. MK45 4HS
National Institute for Research in Dairying	Shinfield, Reading, Berks. RG2 9AT

* National Vegetable Research Station	Wellesbourne, Warwick CV35 9EF
* Plant Breeding Institute	Maris Lane, Trumpington, Cambridge CB2 2LQ
* Rothamsted Experimental Station	Harpenden, Herts. AL5 2JQ
* Welsh Plant Breeding Station	Plas Gogerddan, Aberystwyth, Cardiganshire SY23 3EB
Wye College, Department of Hop Research	Ashford, Kent TN25 5AH

State-aided Institutes in Scotland:

Animal Disease Research Association	Moredun Institute, 408 Gilmerton Road, Edinburgh EH17 7JH
Hannah Research Institute	Kirkhill, Ayr KA6 5HL
* Hill Farming Research Organisation	Bush Estate, Penicuik, Midlothian EH26 0PH
Macaulay Institute for Soil Research	Craigiebuckler, Aberdeen AB9 2QJ
* Rowett Research Institute	Bucksburn, Aberdeen AB2 9SB
* Scottish Horticultural Research Institute	Invergowrie, Dundee DD2 5DA
* Scottish Institute of Agricultural Engineering	Bush Estate, Penicuik, Midlothian EH26 0PH
Scottish Plant Breeding Station	Pentlandfield, Roslin, Midlothian EH25 9RF

* There has been collaboration during the year between these Institutes and the S.P.B.S.

REPORT

to the

FIFTY-EIGHTH ANNUAL GENERAL MEETING

of

THE SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING

26th July 1979

by the

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J. B. D. HERRIOTT, *Convener.*
G. CLAPPERTON.
A. J. CLARK.
Prof. G. R. DICKSON.
J. R. ROBERTSON.
Prof. M. M. YEOMAN.
CHAIRMAN (*ex officio*).
VICE-CHAIRMAN (*ex-officio*).

3. Cereals Research Committee

A. PATTULLO, *Convener.*
W. S. KING.
Sir DAVID LOWE.
G. H. MILLAR.
D. A. J. RANDALL.
C. G. SPENCE.
Prof. M. M. YEOMAN.
CHAIRMAN (*ex-officio*).
VICE-CHAIRMAN (*ex-officio*).

4. Potato Research Committee

W. H. M. GILL, *Convener.*
J. M. FELL.
Mrs B. A. GORDOC.
M. D. HENDERSON.
J. McFARLANE.
J. M. ROY.
C. D. SCOTT.
G. A. STORRAR.
J. M. TODD.
CHAIRMAN (*ex-officio*).
VICE-CHAIRMAN (*ex-officio*).

5. Farm Advisory Committee

G. CLAPPERTON, *Convener.*
J. McFARLANE.
A. PATTULLO.
C. G. SPENCE.
G. A. STORRAR.
CHAIRMAN (*ex-officio*).
VICE CHAIRMAN (*ex-officio*).

ADMINISTRATION

Membership

At 31st March 1979 the total membership was 325, comprising 227 Life Members and 98 Annual Members. Eighteen new members were elected during the year, and eighteen died or resigned.

Meetings

The Board of Directors met on seven occasions during the year, these being on 13th April 1978, 8th June 1978, 27th July 1978, 16th November 1978, 7th December 1978, 15th January 1979, and 15th March 1979.

The Finance Committee, the Research Committees and the Farm Advisory Committee met during the year on the dates shown below:—

Finance Committee	8th June 1978
Brassica Research Committee	24th October 1978
Cereals Research Committee	3rd November 1978
Potato Research Committee	23rd November 1978
Farm Advisory Committee	4th May 1978

Board of Directors

Messrs. Jas. D. G. Davidson, M.V.O., M.I.Ex., G. B. R. Gray, Jas. McFarlane, Wm. H. Porter, D. A. J. Randall, and Mrs B. A. Gordon, B.Sc., (Agric.) demitted office as Ordinary Directors during the year in accordance with the provisions of the Society Rules.

New Ordinary Directors elected at the Annual General Meeting held on 27th July 1978 were Messrs. M. Douglas Henderson, W. S. King, A. Gordon Porter, J.P., and G. A. Storrar, M.C., B.Sc. (Agric), J.P.

Messrs. Jas. McFarlane, D. A. J. Randall, and Mrs B. A. Gordon were co-opted as Directors, in accordance with the Rules, during the course of the year.

The undernoted Ordinary Directors are due to retire from the Board during July 1979:—

John M. Fell, 78 High Street, Boston, Lincolnshire.

W. H. M. Gill, Rosskeen, Invergordon, Ross-shire.

J. B. D. Herriott, B.Sc., Ph.D., Edinburgh School of Agriculture, West Mains Road, Edinburgh EH9 3JG.

Sir David Lowe, C.B.E., D.Sc., F.R.S.E., F.R.Ag.S., Elvingston, Gladsmuir, East Lothian.

C. D. Scott, Waterside, Newburgh, Aberdeen.

C. G. Spence, Biel, Dunbar, East Lothian.

FIFTY-SEVENTH ANNUAL GENERAL MEETING

MINUTE OF PROCEEDINGS AT THE FIFTY-SEVENTH ANNUAL GENERAL MEETING OF MEMBERS OF THE SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING, held at Pentlandfield, Roslin, Midlothian, on Thursday, 27th July 1978.

Mr John Arbuckle, O.B.E.,
Barony Cottage, Newburgh, Fife, presided.

Minute. The Minute of the 56th Annual General Meeting, held at the Scottish Plant Breeding Station on Thursday, 21st July 1977, having been circulated prior to the meeting, was taken as read and was approved and signed.

Apologies. Apologies for absence were intimated by the Secretary.

Annual Report and Accounts. The 57th Annual Report of the Directors embodying the audited accounts for the year ended 31st March 1978 which had been distributed to members before the meeting was submitted by the Chairman.

After a brief speech the Chairman moved and Mr James Gray, O.B.E., T.D., Dalrannoch, Bridge of Allan, Stirlingshire, seconded the adoption of the Report and Accounts and the motion was carried unanimously.

Election of Directors. A motion by Mr A. Pattullo, M.C., J.P., Littleton of Airlie, Kirriemuir, Angus, seconded by Mr G. Clapperton, Sherriffhall Mains, Dalkeith, EH22 1RX, was unanimously adopted to elect to the Board of Directors the following members:—

M. Douglas Henderson, Carse Farmhouse, Aberfeldy, Perthshire.
W. S. King, Tignadarroch, Pencaitland, East Lothian.
A. Gordon Porter, East Scryne, Carnoustie, Angus.
G. A. Storrar, M.C., B.Sc., J.P., Rossie, Auchtermuchty, Fife.

Appointment of Auditors. On the motion of the Chairman, seconded by Mr A. J. Clark, B.Sc., Cast Farm, Leuchars, Fife, Messrs Brown, McDonald and Fleming were re-appointed Auditors of the Society.

This concluded the business of the meeting.

In the informal part of the meeting, the Chairman in his address to members said that the introduction of demonstrations and lunch had given a new dimension to the day of the Annual General Meeting. He hoped that members had found them both enjoyable and instructive. Mr Arbuckle went on to congratulate the staff on their presentations and on the appearance of the Station.

Referring to the Working Party that has been set up to investigate the future requirements of Crop Research in Scotland under the Chairmanship of

Mr W. W. Gauld, Mr Arbuckle said that the Board and himself, personally, welcomed the initiative that had been taken and that he was proud and privileged to have been appointed to be a member of the Working Party. He was looking forward to the wide ranging discussions that would take place and as he had many "hats" to wear as a producer, a consumer or as Chairman of the Society he would endeavour to be as impartial as possible. He hoped that the report, when issued, would be helpful to all concerned.

Mr Arbuckle went on to say that during the year the facilities of the Station have been improved and this was done despite the difficult financial situation of the U.K. economy. The Brassica/Agronomy building was a great benefit to the Station and there had been further investment at the Murrays which was making steady progress towards the aim of making it an international centre of research and development.

Once again, Mr Arbuckle was able to report success for the Potato Division. Following recommendation for the variety Croft in 1977, Pentland Squire has been added to the NIAB list, with a provisional recommendation, this year. Pentland Squire is a useful additional variety and many UK farmers have already had the opportunity of growing it. Some 3,726 hectares of Pentland Squire have been planted in Britain during 1978 against 1,347 hectares in 1977. The variety has also shown promise overseas particularly in Spain. Potato varieties from SPBS now occupy approximately 40 per cent of the total potato acreage in the UK.

The Chairman reported that following the rationalisation decisions taken in 1977, the work on grass and clover has been transferred to WPBS, Aberystwyth. The Department has also fulfilled its obligation to establish a grass screening programme for Scotland which is now in operation at East Craigs.

The release of staff by this exercise has enabled SPBS to expand its programmes on Brassicas and Cereals. The Board appreciate the acceptance of new roles by the staff members who have been involved in the changes.

Professor J. P. Cooper, F.R.S., who is the Director of WPBS, Aberystwyth, gave the Eighth SSRPB Lecture in April 1978 and outlined his views on the future of grass breeding in the UK.

Mr Arbuckle then thanked his fellow Directors for their continuing support. He said that Directors willingly gave of their time to serve on the Board and upon its various committees. The Research Committees now meet once each year to review the future research programmes and to monitor the progress that has been made. He went on to particularly thank the retiring members of the Board, Mr Davidson, Mr Griffin, who has served as Convener of the Cereals Committee, Mrs Gordon, Mr McFarlane and Mr Porter. He also mentioned Mr Scarlett who retired as a Trustee last year. Mr Scarlett, who celebrated his ninetieth birthday on 7th July 1978, still takes a close interest in the affairs of the Society. Appropriate messages and flowers were sent to mark the occasion.

The Chairman said that during the year he had, on behalf of members of the Society, maintained close links with DAFS and he was delighted that Mr W. W. Gauld was present to represent the Department. He recorded his pleasure at the splendid relationship that existed between the officers at the Department and the Society and also thanked the Department for its continuing generous financial support.

Mr Arbuckle concluded by thanking the staff for their efforts during the past year and also praised Dr Macer who, he said, was now beginning to see some return for the drive and enthusiasm that he put into his job as Director of the Station.

Dr Macer in his report to members said that he and his colleagues welcomed the setting up of the Working Party and he looked forward to receiving its report.

He went on to say that the past year has seen many changes with the new buildings provided for Brassica, Agronomy and Potato Pathology, including Nematology. The Chemistry laboratories have also been expanded and upgraded and now provide pleasant and safe working conditions for the staff.

The whole research programme of the Station has been reviewed. It now contains a greater emphasis on pathology in the three main crops, Potatoes, Cereals and Brassicas. The revised programme has been approved by the Agricultural Research Council and commissioned by DAFS.

The transfer of Grasses and White Clover to WPBS under the rationalisation proposals has allowed an expansion of the Station's efforts on Brassicas and on Agronomy and along with new appointments and staff regroupings, new breeding teams have been formed.

This reorganisation has resulted in a more practicable research programme which is fully in accord with JCO recommendations.

The Director said that the lack of suitable and conveniently sited land for carrying out the experimental work was still a major problem. Although improvements have been made to the Murrays with new drainage, improved roads and general cleaning up of the land, the various soil types on the farm and the distance, some thirteen miles from Pentlandfield, made it difficult for the breeders to complete satisfactory trials.

Strenuous efforts had been made to find suitable land for trials on the Bush Estate, but for biological and climatic reasons, a return to the Estate would not be possible. Alternative solutions must be sought and a scheme for rebuilding at the Murrays has been prepared should it be decided to concentrate more work there.

Dr Macer then referred to the provisional recommendation of Pentland Squire by NIAB. He said that this recommendation was a notable achievement and means that an early maincrop potato variety with the following characteristics is available to the farming community:—

(*a*) Yield potential comparable with the very high yielding variety, Pentland Crown;
(*b*) high dry matter content;
(*c*) good table and processing quality; and
(*d*) immunity to viruses X and A.

The Director in thanking Mr Whitehouse, Dr England and the Editorial Committee for their work in producing the Annual Report drew attention to the review article on Brassicas by Dr I. H. McNaughton and Mrs C. L. Ross and the short history of the Murrays by Mr G. R. White. He went on to say that the slight changes in the format of the report had again improved the presentation.

Turning to the future, Dr Macer said that Plant Breeding was entering a new era. The success of conventional breeding approaches in the UK could not be denied. The achievements in potato breeding at SPBS, wheat breeding at PBI and grass breeding at WPBS plus the similar developments at other ARS and Private Sector Stations have proved that improvements can continue to be made by these techniques despite forecasts some time ago that a plateau would be reached.

New opportunities, however, are now available to plant breeders. SPBS is a leader in some areas such as wide-crossing in the Brassicas or in resynthesising the potato by the introduction of Neo Tuberosum. In other areas of

breeding, however, new developments must be applied. For example, there was now a greater understanding of bio-chemical and physiological functions in plants. This understanding may have a particular significance to nitrogen metabolism and to carbohydrate distribution and storage in plants. Also the whole area of genetic manipulation and genetic engineering is passing through the pioneering stage. Fundamental work is being carried out within the ARS, and may soon offer the potential of introducing greater diversity into the breeding programmes. Breeding Stations must be in a position to use the information from these studies. These new techniques may have special relevance in developing plants for the more difficult climates such as the north of the UK.

Breeding programmes are both expensive and long term, they must be large to be successful and they need to be well planned and serviced. Plant Breeders always have to look fifteen to twenty years ahead, therefore cost effectiveness is becoming increasingly important and the efficiency of selection procedures becomes vitally important. The demonstrations on display in the laboratories showed some aspects of improvements in these techniques, in particular new analytical procedures by miniturisation, mass production and making greater use of computers. These tendencies in selection procedures will develop more in the future.

At SPBS we are looking forward to the next few months during which we hope to define our objectives even more precisely and to improve our effectiveness still further.

Mr W. W. Gauld of the Department of Agriculture and Fisheries for Scotland in his address to the meeting said that the regular attendance of representatives from the Department to the AGM confirmed the close and cordial relationship, not just purse and apron strings, between DAFS and the Research Institutes that it supports.

Mr Gauld was pleased to note that the Chairman and Director both recognised that the Department had fulfilled its obligations to the Society, by the provision of new buildings and financial support generally.

He went on to say that he had found the Brassica plots in Threshey Park and the various demonstrations within the main building very impressive. He also noted the general improvement in the Station as a whole and the considerable advance that had been made towards bringing the Murrays up to a standard suitable for international research. The aspects of the Station's work that were on view today embodied both plant breeding and related sciences. These showed the range of activities that are necessary in a modern plant breeding station.

Mr Gauld then drew attention to the impressive achievements of the State-sponsored plant breeding stations and in particular to the fact that 40 per cent of the potato ware acreage is now occupied by varieties produced by the Scottish Plant Breeding Station. This was very encouraging and he sincerely assured the meeting that the Department, who had every confidence in the Board, Director and staff of the Station, would continue to do all it could to foster Scottish arable farming through research and development. It was well aware of the importance and long-term nature of plant breeding.

On referring to the Working Party, Mr Gauld said he was pleased that Mr Arbuckle would be a member of this group as he was a knowledgeable and wise man who would look after the interests of the community as well as the Society.

The various interested parties to this exercise, the Department, the two Institutes and the ARC agreed that a look at the structure and direction of

crop research in Scotland is timely. There are no preconceived ideas or obvious solutions up the Department's sleeve; if there were there would be no need for the Working Party. The aim of the exercise is to ensure that the structure of the Institutes, the staff, the buildings and the land will meet the needs of crop research for the next twenty years and also that the direction of research and the breeding effort meets the JCO requirements and has the necessary scientific support. There are areas where the existing programmes of the SHRI and SPBS touch and it is right that they should be looked at together to ensure the Scottish effort in plant breeding is effective and worthwhile.

Mr Gauld did not envisage the Working Party undertaking a vast and laborious exercise, however they would visit the two Stations and their farms, would have discussions with the Governing bodies and staffs (senior management, staff association and unions). They would want to consider only the broad outline, not details. This would enable recommendations, decisions and adjustments to be made and agreed quickly with all interested parties.

Staff will then be able to get on with the research and development of new crop varieties, better husbandry and improved disease control.

What the Department is concerned with is to ensure that they are asking the scientist the right questions and that the structure, and organisation of the Scottish sector of state funded crop research is such that our scientists are in a position to have every reasonable opportunity to answer the questions posed to them. Research is a long-term exercise. We are not looking only at the problems of farmers today, but must look towards the problems they may have to face in the year 2000.

Our arable growers are faced, because of the Scottish climate, with tough growing conditions. We must, therefore, ensure that the research services can give them the best possible support. The record of the plant institutes to date is excellent and the Working Party must ensure a structure that will enable our successors a quarter of a century hence to make the same proud claim.

In moving a vote of thanks to the Chairman, Professor G. R. Dickson said that the Society was extremely fortunate to have a man of Mr Arbuckle's stature and calibre as its Chairman.

The Ninth SSRPB Lecture:

FROM FERTILIZER NITROGEN TO GRAIN PROTEIN: CONSTRAINTS AND OPPORTUNITIES

Delivered on the 5th April 1979, by

Dr L. FOWDEN, F.R.S.
Director of Rothamsted Experimental Station

Of ten major and several minor nutrients that plants require, nitrogen represents the element whose deficiency most frequently restricts crop growth and yield. It is against this background that the extensive studies of environmental, agronomic, and intrinsic genetic and metabolic factors governing the uptake, assimilation and ultimate distribution of nitrogen within the tissues of plants are justified. Such research seeks principally to improve the efficiency with which fertilizer nitrogen is utilized by crops and to attain maximum translocation and storage of nitrogen as protein in the harvested organ (Fowden, 1979).

NITROGEN, DRY MATTER AND PROTEIN YIELDS

Dry matter yields, protein yields, inputs during crop cultivation and the ultimate profitability of a crop show very complex interrelationships. Protein production per hectare is normally much higher from well managed grass or grass-clover leys and from brassica crops that from cereal grains (Joint Consultative Organization, 1976). Field beans, currently out of favour with farmers as unreliable and therefore likely to be uneconomic, normally give protein yields considerably in excess of those derived from wheat or barley. These differences between crops become more exaggerated when protein yield is expressed in terms of units of fertilizer-N input. Nevertheless, this short account will be concerned only with protein production by cereals, so reflecting their predominant position in arable farming in Britain and also in Rothamsted's programme of research.

Generally, the British climate suits the production of high grain yields. It is less suited to the production of high-protein grain, which is favoured by hotter, drier weather experienced in many other countries during the grain filling and ripening period: these latter climatic conditions usually are associated with much lower dry matter yields. In the UK, the climate more frequently favours the production of wheat for biscuit-making than for bread flour, and of barley for brewing than for high quality feed. If Britain is to

progress towards greater self-sufficiency in the production of bread-making wheats and protein feedstuffs, it is important to appreciate how far other factors can enhance the protein content of cereal grains. Bingham and Blackman (1978) conclude that there are major genetic limitations to breeding for higher cereal grain protein contents; they suggest that environmental and cultural effects, over a normal range of agricultural conditions, may produce differences in protein levels that are more than double the heritable difference between varieties. A new and detailed analysis of the results of a very large number of field experiments performed with winter and spring wheat and spring barley by Rothamsted staff between 1955-1973 amply confirms this view.

This new evaluation of data was made with support from the Home Grown Cereals Authority (Benzian and Lane, 1979). Here, only the examination of 124 experiments with winter wheat will be cited. Their main purpose was to discover methods, which alone or in combination would produce an increase in grain yield. Cappelle-Desprez was the variety used in more than 70 per cent of the experiments, a quarter of which were performed on commercial farms. The experiments varied greatly in the number and type of manuring treatments, and in duration and complexity of design. All experiments tested levels of nitrogen, many compared methods and times of fertilizer application, some tested forms of fertilizer, and a few tested fertilizer residues. The effects of cropping sequence and soil type formed part of the survey, and weather represented an external factor showing considerable seasonal variation over the 18-year period. Grain yields (at 85% DM) and associated N concentrations (in DM) varied between wide limits: the co-ordinates, about 2000, are contained within the envelope shown in Figure 17. Yields ranged from 1·0 to 9·5 t ha^{-1} (Rothamsted achieved its first 10 t ha^{-1} yield of wheat in 1978), and per cent N from 1·2 to 3·0. The exceptionally high single value of 3·0 per cent N lies outside the envelope, but has been confirmed by independent analysis; it relates to a 1973 grain sample from a farmyard manure + fertilizer N plot on the Broadbalk classical whea experiment. The largest amount of protein produced in the series of experiments was 925 kg ha^{-1} (conversion factor 5·7 × Kjeldahl N). The desirable combination of high yield with high per cent N in grain needed for bread making is favoured by growing a preceding legume crop or grass ley; furthermore, half the grain samples having co-ordinates in the top right-hand section of the envelope (yield > 5·5 t ha^{-1}, per cent N > 2·0) came from the experiments receiving > 120 kg N ha^{-1}. When the co-ordinates obtained from experiments performed in fewer seasons on the light sandy soil at Woburn Experimental Station are plotted separately the envelope circumscribing the cumulative data is considerably smaller, the maximum yield being just less than 6 t ha^{-1}.

Seasonal effects upon yield and composition can be very marked, and undoubtedly contribute substantially to the wide scatter of points contained within the envelope of Figure 17. Support is provided by Bowerman and

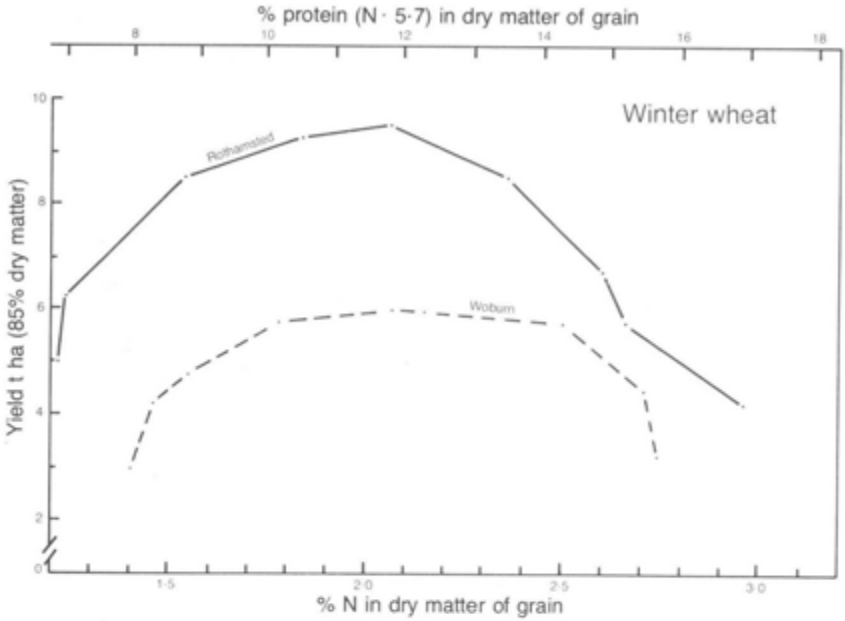


Figure 17 shows a diagrammatic representation of the envelopes within which all data fall relating to grain yield and grain protein content of samples of winter wheat harvested from experiments at Rothamsted and Woburn performed between 1955 and 1973.

Clare (1976) who reported differences of up to one per cent in the N content of winter wheat grown under similar fertilizer-N treatments over three seasons (1971, 1972 and 1973), at the Boxworth Experimental Husbandry Farm of ADAS: dry matter yields varied in an inverse manner so that protein yields for a given N application remained approximately constant in the three seasons. Farmers remember that the exceptionally hot summer of 1976 was associated with severely water-stressed cereal crops and lowered yields, but millers and brewers recall the year as one of unusually high grain protein levels.

NUTRIENT EFFECTS ON PROTEIN COMPOSITION

Cereal proteins have low nutritional qualities primarily because they contain too little lysine. Factors leading to increased grain protein levels, including high N applications, normally produce an associated increase in the proportion of prolamin-type storage proteins in the grain. Because gliadin from wheat shares with other cereal prolamins the common property of low lysine content, grain protein content tends to be inversely correlated with the percentage of lysine present in the protein. Sulphur is another nutrient that can profoundly influence cereal yields and composition. Yield effects attributable to sulphur limitation may occur when wheat or barley receive high nitrogen treatments. Reductions of yield resulting from low S/N nut-

rient ratios have been recorded only rarely for field grown cereals, mainly because older types of fertilizers and industrial atmospheres provided sufficient sulphur. The decreased use of ammonium sulphate and superphosphate fertilizers and reduced atmospheric pollution will lead to a gradual fall in S levels in agricultural soils, and instances of S deficiency such as those observed in South-East Scotland could become more common. Experiments at Rothamsted with spring wheat grown in glasshouses and in controlled environment cabinets with air filtration demonstrated dramatic yield reductions at high levels of N fertilization when no S was added to soils (Byers and Bolton, 1979): associated changes included a much increased per cent N and a slightly lower per cent S in grain, markedly reduced percentages of cyst(e)ine and methionine in the grain protein, and the predictable reduction in the lysine content of protein as the per cent N and protein levels of grain increased (Tables 26 and 27). The very significant changes in lysine, cyst(e)ine and

TABLE 26

Yield and composition of pot-grown† spring wheat given four levels of N and two levels of S (growth cabinet experiment).

		Yield (g DM per 5 plants)		*%N in grain DM*		*Lysine††*	
N (mg/pot)	*S (mg/pot)*	0	30	0	30	0	30
60		2·94	2·90	1·15	1·00	3·95	3·95
120		2·90	4·60	1·86	1·10	2·74	3·92
180		1·18	5·65	2·55	1·38	2·48	3·62
240		0·80	6·35	2·82	1·80	2·35	3·26

†Soil was a S-deficient sandy loam from Woburn Experimental Station.
††as g per 100g recovered amino acids in grain.

TABLE 27

Composition of pot-grown† spring wheat given three levels of N and no additional S.

Nitrogen (mg/pot)	*% N in grain DM*	*% S in grain DM*	*N/S ratio*	*Cyst(e)ine††*	*Methionine††*	*Cys/Meth Ratio*
100	1·75	0·12	14·6	2·91	1·67	1·74
200	2·62	0·11	23·8	1·73	1·23	1·41
300	3·43	0·09	38·1	1·24	0·83	1·49

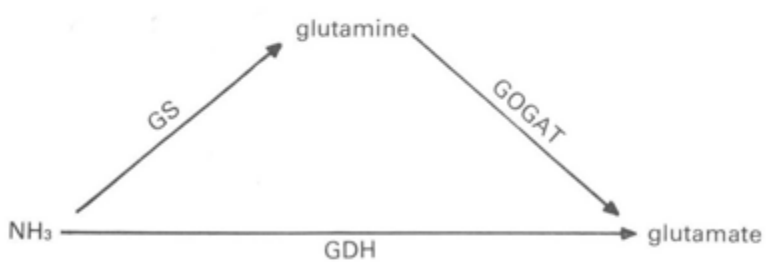
† Soil was a S-deficient sandy loam from Woburn Experimental Station.
†† as g per 100g recovered amino acids in grain.

methionine contents must be associated with considerable changes in the proportions of the different protein species constituting the total grain protein: the diminished content of cyst(e)ine, and the associated reduction of disulphide cross-links in the protein, results in flours of lower bread-making quality.

Plant roots take up inorganic forms of nitrogen, principally nitrate, from soils and use this nitrogen in the formation of the many essential nitrogenous compounds constituting plant cells; the majority of the nitrogen, however, is destined to be incorporated into protein molecules. The biochemical pathways involved in these conversions are being intensely studied on the premise that a fuller understanding of the mechanisms regulating the flow of nitrogen might be expected to provide new opportunities for manipulating these processes to produce plants with more desirable characteristics e.g. grain containing more protein of higher nutritional quality.

The pathway for assimilation of inorganic nitrogen has the following clear stages. Nitrate is first reduced via nitrite to ammonia; ammonia enters organic combination as glutamine and glutamate; glutamate then acts as a precursor providing the amino-N group for the formation of other amino acids, and finally protein is synthesized from this pool of free amino acids. Other nitrogenous constituents of plants are derived from individual members of the amino acid pool. Members of the Biochemistry Department at Rothamsted are studying the detailed pathways and enzyme regulatory mechanisms involved in certain of these processes.

It has become clear recently that alternative pathways for the assimilation of ammonia into glutamate exist in different organisms (Miflin and Lea, 1977). Earlier, assimilation was considered invariably to occur by one-stage process catalyzed by the enzyme glutamic dehydrogenase (GDH), but now this mechanism is thought to be predominant only in the fungi. Higher plants, and bacteria, adopt a two-step process in which ammonia is first introduced as the amide group of glutamine, which in turn transfers this amide-N to glutamate: the reactions are catalyzed by the enzymes glutamine synthetase (GS) and glutamate synthetase (GOGAT), respectively. Emphasis of this biosynthetic dichtomy may appear as an example of biochemical semantics, but the distinct and rather rare difference of enzymic mechanisms between green plants and fungi in a major assimilatory process could provide a future opportunity for the specific inhibition of fungal pathogen development.



Although at first it may seem a digression, it is relevant here to mention photorespiration, a process occurring in temperate C3 species and one

counter-productive to photosynthesis. Determination of photorespiratory CO_2 production by wheat plants indicates that the losses of carbon may range up to 53 per cent of that fixed by photosynthesis (Keys *et al*, 1977); a consequential deleterious effect on yield is inferred. This adverse aspect of photorespiration is widely recognized, but the liberation of ammonia in amounts equal to the CO_2 released tends to go unnoticed. Both compounds are formed, together with an equimolar quantity of serine, from two molecules of glycine during the photorespiratory process. New evidence suggests that the flux of ammonia through the photorespiratory cycle is of an order of magnitude greater than that resulting from the primary assimilation of nitrate (Keys *et al*, 1978). Reassimilation of the photorespiratory ammonia apparently involves the combined action of GS and GOGAT, and probably occurs largely in the chloroplast where the energy-demanding steps are driven indirectly by light energy. Nevertheless, this cycling of ammonia through the photorespiratory cycle appears to be a potentially wasteful process and may exercise an additional constraint on yield and protein production.

REGULATION OF AMINO ACID SYNTHESIS

Except in abnormal circumstances, the concentrations of most free amino acids in plant cells are maintained within narrow limits, but in sufficient amounts to sustain protein synthesis. As we have recognized earlier, certain amino acids are required and synthesized by plants in amounts too small to provide man and animals with nutritionally-balanced protein e.g. cereal grains are deficient especially in lysine whilst legume seeds contain little of the sulphur-containing amino acids, methionine and cysteine. For this reason it is important to gain a fuller understanding of the control mechanisms operating within plant tissues that serve to regulate the rates of synthesis of such amino acids. Lysine and methionine are respective end-products of a branched biosynthetic pathway commencing from aspartate (see diagrammatic representation in Figure 18). Seven steps, each catalysed by a

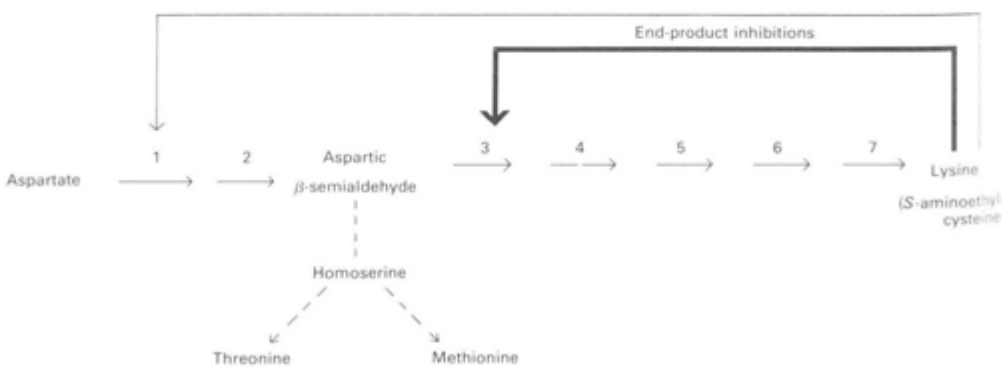


Figure 18 shows in outline the biosynthetic pathway used by green plants to produce lysine from aspartate and the points where end-product inhibition operates.

specific enzyme, result in lysine production. Like many pathway end-products, lysine acts as an inhibitor of enzymes operating in its own synthesis — in this case on the enzymes catalyzing the first and third reactions in the sequence, but especially strongly on the third enzyme acting immediately after the branch point of the pathway (Mazelis *et al*, 1977; Bright *et al*, 1978). Since higher cellular concentrations of lysine will cause stronger enzyme inhibitions and thereby a greater reduction in the rate of synthesis of new lysine molecules, the necessary conditions for a delicate system of auto-regulation of cellular concentrations of lysine exist.

Certain molecules showing close structural similarity to lysine (1)

$$CH_2(NH_2)CH_2CH_2CH_2CH(NH_2)COOH \qquad (1)$$

may mimic its role as an end-product inhibitor, whilst being unable to substitute for it in protein molecules with retention of their biological activity. S-Aminoethylcysteine (2) is an example of such an analogue

$$CH_2(NH_2)CH_2SCH_2CH(NH_2)COOH \qquad (2)$$

molecule. The analogue then behaves as a growth inhibitor because in its presence cells become starved of lysine. This behaviour provides a mechanism for screening for mutant cell lines that have lost, partially or wholly, the ability to regulate lysine synthesis, for their growth in the presence of the analogue is less inhibited than that of normal cells (Widholm, 1976). This approach has been adopted at Rothamsted to screen excised barley embryos in attempts to isolate lines over-producing lysine. It should be recognized that other resistance mechanisms are possible, e.g. by the failure of cells to take up the analogue, or by mutant lines discriminating against the analogue during protein synthesis and so protecting themselves against abnormal protein production. The present technique using embryos is laborious, and this analogue approach to selection would become much more facile if cereal protoplasts could be screened and resistant types then regenerated into normal plantlets. The regeneration of protoplasts of agriculturally-important species is one of the principal objectives of the new initiative on genetic manipulation of plants supported by the Agricultural Research Council (ARC).

IMPROVEMENT OF GRAIN PROTEIN QUALITY

Protein present in cereal grains consists of a salt-soluble fraction (often referred to as a mixture of albumins and globulins), together with prolamins and glutelins. Prolamins represent the principal storage protein and are characterized by low lysine contents: gliadin, hordein, zein and avenin are prolamins present in wheat, barley, maize and oats respectively. Hordein is being used as a model for studies at Rothamsted seeking to define with greater certainty the polypeptide complex constituting this fraction, to understand how polypeptides are synthesized during development of the barley grain and how their distribution varies between varieties and mutants rich in lysine, and to identify the messenger RNA and the associated sections of the DNA genome directing hordein formation.

The hordein polypeptides in different barley varieties show distinctive patterns (see Figure 19) after separation by gel electrophoresis (Shrewry *et al*,

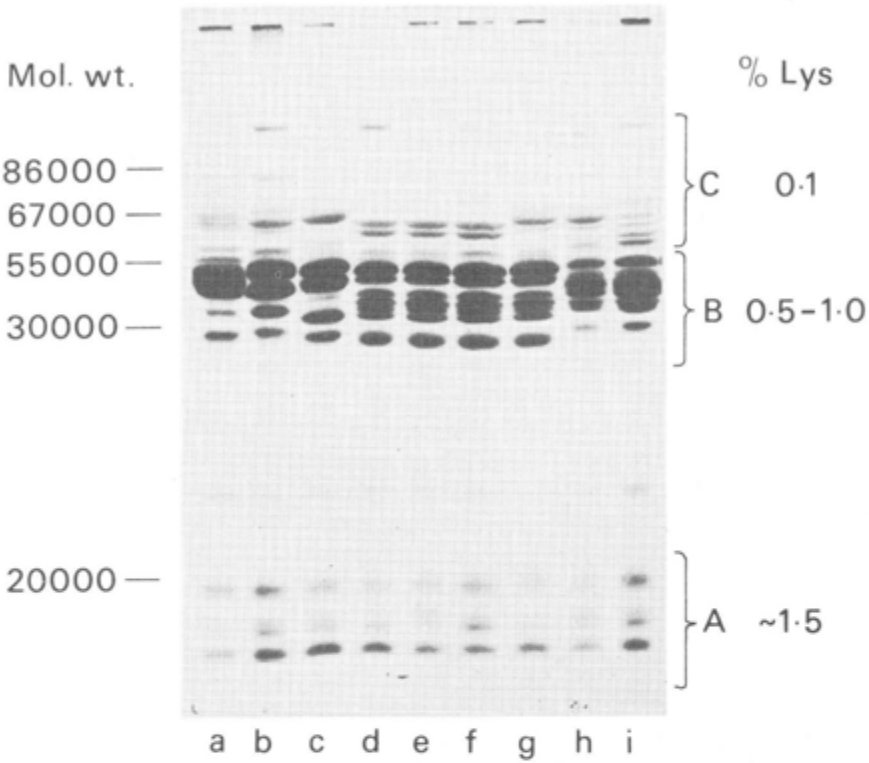


Figure 19 shows a separation by gel electrophoresis of the hordein polypeptides of nine barley varieties: a, Midas; b, Tyra; c, Ark Royal; d, Maris Mink; e, Aramir; f, Maris Trojan; g, Hassan; h, Senta; and i, Sonja.

1978) and electrophoretic techniques would appear to hold the potential for establishing varietal identity on single or half barley seeds in a manner similar to that used in wheat. The polypeptides separate into A, B and C groups. The A polypeptides comprise only one or two per cent of the total hordein fraction, remain almost constant in relative amount in all varieties, and have the lowest molecular weights and contain about 1·5 per cent lysine. The B and C polypeptides show greater intra-group heterogeneity in molecular weight: they also show considerable inter-varietal differences. B polypeptides contain between 0·5-1·0 per cent lysine, but C polypeptides have only about 0·1 per cent.

Rothamsted's work has centred mainly on the barley variety Bomi and its high-lysine mutant, Risø 1508. As with other barley parent-mutant comparisons, the hordein fraction of the high-lysine line constitutes a smaller proportion of the total seed protein than it does in the parent (Table 28). The

TABLE 28

The nitrogenous fractions of normal and high lysine barley lines.

Variety	*Seed lysine*†	*Non-protein N*††	*Salt-sol. protein N*††	*Hordein N*††	*Glutelin N*††
Bomi	3·3	11·6	15·6	45·2	18·0
Risø 1508	4·9	19·9	25·4	15·6	26·5
NP 113	2·9	6·3	13·3	47·3	24·3
Notch 1	3·9	9·3	15·8	32·0	33·8
Notch 2	3·9	11·1	17·1	29·0	32·8
Perga	3·2	8·1	10·9	45·8	22·5
Lys 95	4·1	13·2	11·5	31·2	35·4
Lys 449	4·2	12·1	11·1	35·2	33·6

† as mole % †† as % of total seed N.

marked reduction of hordein in Risø 1508 is associated with increased proportions of each of the other nitrogenous fractions of the seed, but in lys 95 and lys 449 mutants of Perga, compensation for the decrease in hordein is seen mainly as an increase in the glutelin fraction (Shrewry *et al*, 1979). The polypeptide pattern of the high-lysine mutant also differs from that of the parent variety. The relatively lysine-rich A polypeptides represent a much increased proportion of the hordein fraction in Risø 1508 in comparison with Bomi; within the B group, the higher molecular weight species are more prominent in the mutant; and the C polypeptides of Bomi are replaced by different molecular weight species in Risø 1508. These changes, especially the increased amounts of A polypeptides, produce in the mutant a hordein fraction richer in lysine (Rothamsted Experimental Station, Annual Report for 1978).

As part of the joint ARC genetic manipulation programme, biochemists at Rothamsted have shown that polysomes derived from the rough endoplasmic reticulum of developing barley seeds contain the mRNA coding for several of the hordein polypeptides. A mRNA fraction has been isolated from the polysomes, purified by affinity chromatography, and shown to code for the production of polypeptides (using a wheat-germ protein-synthesizing system) having similar electrophoretic mobility to those of authentic hordein. In association with scientists at the Plant Breeding Institute, Cambridge, samples of this mRNA preparation have been reverse transcribed to produce DNA copies. The next stages of the programme will involve treatment of this DNA with restriction enzymes and the cloning in bacteria of the resulting pieces of the DNA. The cloned DNA transcripts should permit the true hordein genes (i.e. with any leader sequences of insertions) from the

nuclear genome to be obtained. Isolated protoplasts are envisaged as the most likely acceptor system for the transfer of such isolated genetic information; therefore, the incorporation of this information into new generations of plants again will depend upon the successful development of techniques for regenerating protoplasts. The hordein polypeptides provide good markers in developing this approach because they can be recognized unequivocably. We hope that these studies will establish principles applicable to the transfer of other genetically-controlled characters between sexually incompatible plant species.

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ABSTRACT OF ACCOUNTS

INCOME AND EXPENDITURE ACCOUNT

for year ended 31st March 1979

1978				
	Income			
	Department of Agriculture and Fisheries for Scotland—			
£802,000	Maintenance grants			£936,360
101	Annual subscriptions			100
2,280	Other income			978
£804,381				£937,438
	Less *Expenditure*			
	Scientific and technical staff salaries, wages and			
£454,850	National Insurance contributions		£511,899	
21,799	Implements and apparatus		20,452	
42,663	Other research expenditure		54,311	
6,648	Staff recruitment and training		7,526	
44,971	Additions to fixed assets (see note 1)		51,885	
88,701	Property and buildings (see note 2)		100,555	
34,386	Travel and transport		39,731	
	Administration and office expenses (including			
53,018	salaries etc. £37,208; 1978 £35,253)		58,043	
12,420	Pensions and supplementation		14,982	
	The Murrays Farm—			
44,445	Net operating cost	£50,576		
46,607	Improvements	34,116		
		£84,692		
	Less capital grants from Department of Agri-			
(46,607)	culture and Fisheries for Scotland	34,116		
			50,576	
803,901				909,960
£ 480	Unexpended balance of maintenance grant carried to Balance Sheet (see note 3)			£ 27,478

BALANCE SHEET

as at 31st March 1979

1978					
		Fixed Assets (see note 4)			
	£829,585	Heritable property		£904,311	
	182,594	Capital equipment		219,553	
£1,012,179					£1,123,864
		Current Assets			
	—	Stock		£ 80	
	£ 2,296	Sundry debtors and deposits		5,402	
	30,825	Cash and bank balances		55,063	
	£ 33,121			£ 60,545	
		Less *Current Liabilities*			
	£ 606	Sundry creditors	£ 552		
		Department of Agriculture and Fisheries for Scotland— Unexpended maintenance grants			
	32,023	(see note 3)	59,501		
	£ 32,629			60,053	
492					492
£1,012,671					£1,124,356
		Represented by			
£ 861,794		Funds as at 1st April 1978			£1,012,671
		Add grants received from the Department of Agriculture and Fisheries for Scotland—			
	£119,725	Capital works		£ 74,726	
	32,676	Capital equipment		36,959	
	£152,401			£111,685	
	1,524	Less fixed assets written off		—	
150,877					111,685
£1,012,671					£1,124,356

JOHN ARBUCKLE, *Convener, Finance Committee.*

NOTES TO INCOME AND EXPENDITURE ACCOUNT AND BALANCE SHEET

(Year ended 31st March 1979)

1. Additions to fixed assets—

Laboratory apparatus	£ 24,930
Implements and equipment	12,709
Safety equipment	464
Library books etc.	4,763
Motor vehicles	5,231
Furniture and fittings	3,788
	£ 51,885

2. Property and buildings—

Rent and rates	£ 21,153
Edinburgh Centre of Rural Economy	8,595
Property improvements, alterations and repairs	15,569
Power, light and heat	55,238
	£ 100,555

3. Unexpended maintenance grants—

Balance brought forward at 1st April 1978	£ 32,023
Addition during year	27,478
Balance carried forward at 31st March 1979	£ 59,501

4. Fixed assets as at 31st March 1979—

	Cost	*Less charged to Revenue*	*Net*
Heritable property	£ 904,311	—	£ 904,311
Capital equipment	219,553	—	219,553
	£1,123,864	—	£1,123,864
Implements and tools (including safety equipment)	76,584	£ 76,584	—
Vehicles	31,337	31,337	—
Laboratory apparatus	122,546	122,546	—
Furniture and fittings	26,518	26,518	—
Library books	20,277	20,277	—
	£1,401,126	£277,262	£1,123,864

FUNDS AND BEQUESTS

INCOME AND EXPENDITURE ACCOUNT

for year ended 31st March 1979

1978				
		Income		
		Gross interest and dividends on investments (see note 1)—		
	£1,042	Narrower range	£1,006	
	1,036	Wider range	1,178	
£2,078				£2,184
46		Interest on bank deposit accounts		77
448		Profit on realisation of investments		639
220		Life subscriptions		50
50		Donations		75
£2,842				£3,025
		Less *Expenditure*		
	£ 4	Registrar of Friendly Societies	£ 7	
	176	S.S.R.P.B. lecture	141	
	124	Retirement/resignation presentations	80	
	453	Travel grants and travelling expenses	388	
	180	Donations	180	
	32	Hospitality	107	
	75	Bank charges	165	
1,044				1,068
£1,798		Net revenue carried to Balance Sheet		£1,957

FUNDS AND BEQUESTS

BALANCE SHEET

as at 31st March 1979

1978		*Narrower range*	*Wider range*	
	Assets			
	Investments at cost (see note 2)—			
£15,145	Life Membership Subscriptions and Donations Fund	£ 7,320	£9,250	£16,570
2,555	W. J. Reid and James Munro Bequests	2,099	757	2,856
600	Dr Wilson Memorial Fund	381	348	729
2,097	J. C. Thyne Bequest	1,049	1,048	2,097
£20,397				£22,252
712	Recoverable income tax		£ 725	
145	Sundry debtors		—	
2,257	Bank of Scotland—current and deposit accounts		2,712	
			£3,437	
—	*Less* sundry creditors		220	3,217
£23,511				£25,469

	Represented by	*Funds at 1st April 1978*	*Net revenue for year*	
£17,040	Life Membership Subscriptions and Donations Fund	£17,040	£1,691	£18,731
3,103	W. J. Reid and James Munro Bequests	3,103	235	3,338
814	Dr Wilson Memorial Fund	814	56	870
2,554	J. C. Thyne Bequest	2,554	(24)	2,530
£23,511				£25,469

FUNDS AND BEQUESTS

NOTES TO INCOME AND EXPENDITURE ACCOUNT AND BALANCE SHEET

1. Full details of gross interest and dividends received are given in the appended schedule.
2. Full details of the investments appertaining to each Fund are given in the schedule. Movements during the year were as follows—

	Book value	*Sale proceeds*
Realisations		
Life Membership Subscriptions and Donations Fund—		
Wider range—		
1,161 ord. 25p shares Imperial Group	£ 291	£930
Purchases		
Life Membership Subscriptions and Donations Fund—		
Narrower range—		
£494·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£ 349	—
Wider range—		
£1,810·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£1,280	—
83 ord. 5p "rights" shares London and Manchester Assurance Co. Ltd.	87	—
	£1,367	
W. J. Reid and James Munro Bequests—		
Narrower range—		
£212·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£ 150	—
Wider range—		
£212·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£ 150	—
Dr Wilson Memorial Fund—		
Narrower range—		
£91·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£ 64	—
Wider range—		
£91·00 Agricultural Mortgage Corporation Ltd. 7¾% D/S 1991/93	£ 64	—

APPENDIX

Investments as at 31st March 1979

LIFE MEMBERSHIP SUBSCRIPTIONS AND DONATIONS FUND ("B" ACCOUNT)

	Book value	*Market value as at date*	*Gross Interest/ dividends for year to date*
(Narrower range)			
£1,581·40 6½% Funding Stock 1985/87	£1,508	£ 1,313	£ 103
£2,359·35 8¾% Treasury Loan 1997	2,254	1,923	206
£450·00 City of Westminster 13% Redeemable Stock 1981	445	463	59
£4,039·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	3,113	2,908	313
	£7,320	£ 6,607	£ 681
(Wider range)			
£450·00 City of Westminster 13% Redeemable Stock 1981	£ 445	£ 464	£ 58
£3,660·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	2,722	2,635	284
413 ord. 25p shares Guardian Royal Exchange Assurance Co. Ltd.	714	1,094	66
1,980 ord. 25p shares National Commercial Banking Group	864	1,980	88
345 ord. 25p shares Shell Transport & Trading Co. Ltd.	1,373	2,605	91
388 ord. £1 stock units Imperial Chemical Industries Ltd.	751	1,552	102
1,420 ord. 50p shares Claverhouse Investment Trust Ltd.	795	1,392	93
913 ord. 5p shares London & Manchester Assurance Co. Ltd.	1,586	1,342	93
1,161 ord. 25p shares Imperial Group	—	—	60
	£ 9,250	£13,064	£ 935
"B" ACCOUNT TOTAL	£16,570	£19,671	£1,616

W. J. REID AND JAMES MUNRO BEQUESTS ("C" ACCOUNT)

(Narrower range)			
£1,359·29 6½% Funding Stock 1985/87	£ 1,334	£ 1,128	£ 88
£150·00 City of Westminster 13% Redeemable Stock 1981	150	155	20
£215·00 English & International Trust Ltd. 7% Convertible Stock 1986	259	204	15
£477·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	356	343	37
	£ 2,099	£ 1,830	£ 160
(Wider range)			
£215·00 English & International Trust Ltd. 7% Convertible Stock 1986	£ 259	£ 204	£ 15
£150·00 City of Westminster 13% Redeemable Stock 1981	149	155	19
£212·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	150	153	16
90 ord. £1 stock units Imperial Chemical Industries Ltd.	199	360	24
	£ 757	£ 872	£ 74
"C" ACCOUNT TOTAL	£ 2,856	£ 2,702	£ 234

DR WILSON MEMORIAL FUND ("D" ACCOUNT)

	Book value	*Market value as at date*	*Gross interest/ dividends for year to date*
(Narrower range)			
£276·60 6½% Funding Stock 1985/87	£ 266	£ 230	£ 18
£91·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	64	65	7
£35·00 English & International Trust Ltd. 7% Convertible Stock 1986	51	33	2
	£ 381	£ 328	£ 27
(Wider range)			
£91·00 Agricultural Mortgage Corporation Ltd. 7¾% Deb. Stock 1991/93	£ 65	£ 66	£ 7
£ 35·00 English & International Trust Ltd. 7% Convertible Stock 1986	51	33	3
133 ord. 25p shares Guardian Royal Exchange Assurance Co. Ltd.	232	352	21
	£ 348	£ 451	£ 31
"D" ACCOUNT TOTAL	£ 729	£ 779	£ 58

J. C. THYNE BEQUEST ("E" ACCOUNT)

(Narrower range)			
£1,060·00 City of Westminster 13% Redeemable Stock 1981	£ 1,049	£ 1,092	£ 138
(Wider range)			
£1,060·00 City of Westminster 13% Redeemable Stock 1981	£ 1,048	£ 1,092	£ 138
"E" ACCOUNT TOTAL	£ 2,097	£ 2,184	£ 276
TOTAL INVESTMENTS	£22,252	£25,336	£2,184
			(9·8% on invested capital)

AUDITORS' REPORT

In our opinion the Income and Expenditure Accounts and Balance Sheets set out on pages 170 to 177 which have been prepared on a historical cost basis give a true and fair view of the state of affairs as at 31st March 1979 and of the income and expenditure for the year ended on that date.

16 Alva Street, Edinburgh.
30th May, 1979.

BROWN, MACDONALD & FLEMING, *Auditors.*

LIST OF MEMBERS

The following information is the latest known to the Society. It would be appreciated if necessary alterations could be intimated to the Secretary.

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Hamilton, James, Hoprig, Cockburnspath.
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THE SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING AND THE SCOTTISH PLANT BREEDING STATION

The Scottish Society for Research in Plant Breeding was founded in 1920 with the dual aims of conducting scientific investigations into plant breeding and of breeding crops for Scottish agriculture. Membership of the Society is open to any interested person whether farmer, merchant, scientist or other, in or out of Scotland (see p. 000 for application form). Its management is vested in a Board of Directors which is partly elected by the members and partly nominated by the Secretary of State for Scotland, and its principal activity is to look after the affairs of the Scottish Plant Breeding Station.

The Station is now financed from public funds granted by the Department of Agriculture and Fisheries for Scotland under scientific advice from the Agricultural Research Council. It was for thirty-three years at Craigs House, Corstorphine, and moved to new premises, Pentlandfield, on the Bush Estate of the Edinburgh Centre of Rural Economy in 1954. In addition to laboratories, glasshouses, and some land at Pentlandfield it now has land and facilities at its experimental centre, the Murrays, in East Lothian (see maps on cover). Field trials are also grown at other sites in Scotland, Wales, England and New Zealand.

The Station is now largely concerned with brassica, cereal and potato crops. Its resources are directed approximately equally towards the elucidation of fundamental aspects of these crops and the breeding of new varieties. It has scientific links with the Edinburgh School of Agriculture, the ARC Unit of Statistics, the Edinburgh Regional Computing Centre, and is a component of the Agricultural research Service.