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# Changing techniques in crop plant classification: molecularization at the National Institute of Agricultural Botany during the 1980s

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**SUMMARY**
Modern methods of analysing biological materials, including protein and DNA sequencing, are increasingly the objects of historical study. Yet twentieth-century taxonomic techniques have been overlooked in one of their most important contexts: agricultural botany. This paper addresses this omission by harnessing unexamined archival material from the National Institute of Agricultural Botany (NIAB), a British plant science organization. During the 1980s the NIAB carried out three overlapping research programmes in crop identification and analysis: electrophoresis, near infrared spectroscopy (NIRS) and machine vision systems. For each of these three programmes, contemporary economic, statutory and scientific factors behind their uptake by the NIAB are discussed. This approach reveals significant links between taxonomic practice at the NIAB and historical questions around agricultural research, intellectual property and scientific values. Such links are of further importance given that the techniques developed by researchers at the NIAB during the 1980s remain part of crop classification guidelines issued by international bodies today.

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## 1. Introduction

In 1995 the National Institute of Agricultural Botany (or NIAB) was the site of an experiment to settle which means of classifying crop plants was the most accurate. Morphological, visual and molecular techniques were all pitted against each other. Electrophoresis, an established form of protein fingerprinting, seemingly provided the 'most efficient discrimination' between varieties. Yet the technique had its problems, including sustained opposition from plant breeders and difficulties in detecting foreign genes. Ultimately, the instigators of the experiment recommended combining different techniques to create an 'integrated' approach to crop analysis and classification.[1] The NIAB had

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[1]G. Mudzana et al., 'Variety discrimination in faba beans (*Vicia faba L.*): an integrated approach', *Plant Varieties and Seeds*, 8 (1995), 135–45.

first begun to adopt new classificatory techniques like electrophoresis during the 1980s. Yet some fifteen years on, deciding upon the best means of classifying crop plants at the Institute was still no easy matter.

The range of different techniques and technologies available at the NIAB by 1995 was testament to the challenges faced in differentiating one crop variety from another. As most crop plants are bred from closely-related stock, differences between them can be minute. As more and more crop varieties are bred, simply telling one variety from the next has become increasingly difficult. Agricultural botany seeks to classify crop plants on specific, commercially valuable qualities: in other words, it is not so much the appearance or ancestry of crop varieties that matters. Instead, agronomic characteristics such as yield, disease resistance and nutritional content are more important in distinguishing one variety from another.[2] Harnessing unexamined sources from the NIAB, this paper argues that changes to late twentieth-century crop taxonomic techniques were not the inevitable result of molecular methods replacing older morphological work. Instead, techniques such as electrophoresis appealed to the NIAB for practical, economic reasons.

The NIAB has operated as a technical centre for variety analysis since its foundation in 1919. Charged with improving the quality and reliability of British seeds following the First World War, NIAB accepted and trialled crop varieties submitted by plant breeders for inclusion on its Recommended List – a list of the most promising crop plants – for growers. Yet the NIAB ran into numerous difficulties in its varietal work during the 1970s. The Institute's workload increased exponentially following the passing of the 1964 Plant Varieties and Seeds Act (providing intellectual property rights for breeders) and European Economic Community (EEC) demands that British varieties conform to and be included in European-style 'National Lists' by 1973.[3] Looking back in 1990 at the history of the NIAB, two of its field officers described how 'the difficulty of identifying varieties as many new ones were introduced' had shaped the Institute.[4] Recent historical work has likewise recognized that agricultural institutions can serve as nurturing spaces for emerging 'biological specialties'.[5] Yet crop classification work has largely gone unrecognized in the history of agriculture.

During the 1980s, a series of technological advances were portrayed as revolutionizing the classification of crop varieties at the NIAB. Computer-aided measurement, spectroscopy, chromatography and protein fingerprinting were all applied to variety classification and analysis. Automation and mechanization possessed a powerful allure for the overworked and underfunded Institute. By the end of the 1980s, the NIAB was creating its own laboratory techniques and standards for biochemical analysis of crop varieties, or 'chemotaxonomy'. NIAB overcame its reputation as a less-than-premier research organization to carve out a niche in the identification and analysis of varieties, particularly through the novel use of electrophoresis (a form of protein fingerprinting). In the words of one of the Institute's biochemists, this research began the NIAB's transition from a 'technical institution to research organization'.[6]

[2]P.D. Keefe and S.R. Draper, 'The measurement of new characters for cultivar identification in wheat using machine vision', *Seed Science and Technology*, 14 (1986), 715–24.

[3]P.S. Wellington, 'Director's Notes for Fellows on the Annual Report and Accounts for 1978', NIAB Fellow's newsletter 76, July 1979, Folder N1-11, National Institute of Agricultural Botany [hereafter referred to as NIAB] Archives. The substantial delay between the passage of the 1964 Act and submission of new varieties to the NIAB occurred as it generally took plant breeders between ten to twelve generations to produce a new variety from an initial cross. For an overview of the history of the NIAB, see Valerie Silvey and P.S. Wellington, *Crop and Seed Improvement: A History of the National Institute of Agricultural Botany 1919 to 1996* (Cambridge: NIAB, 1997). On the Institute's pre-1970 history, see Dominic Joseph Berry, 'Genetics, statistics, and regulation at the National Institute of Agricultural Botany, 1919-1969', PhD Thesis, University of Leeds (2014).

[4]A.F. Kelly and J.D.C. Bowring, 'The development of seed certification in England and Wales', *Plant Varieties and Seeds*, 3 (1990), 139–50 (148).

[5]Jonathan Harwood, 'Introduction to the special issue on biology and agriculture', *Journal of the History of Biology*, 39 (2006), 237–39; Barbara A. Kimmelman, 'Mr. Blakeslee builds his dream house: agricultural institutions, genetics and careers', *Journal of the History of Biology*, 39 (2006), 241–80; Christophe Bonneuil, 'Mendelism, plant breeding and experimental cultures: agriculture and the development of genetics in France', *Journal of the History of Biology*, 39 (2006), 281–308.

[6]Robert J. Cooke, interview with author, 09 March 2015. This institutional transformation was also brought up at a seminar with the NIAB Retirement Group, 21 April 2016.

This paper examines three technologies used or produced at NIAB for crop identification and analysis during the 1980s: electrophoresis, near-infrared spectroscopy (NIRS) and machine vision systems. Electrophoresis initially became the Institute's flagship research programme. Yet, as we have seen, it faced stiff competition from machine vision systems by the late 1980s and 1990s. Tracing the pursuit of different types of classificatory technology at the NIAB reveals underlying commercial and scientific ambitions, and even contemporary visions of future taxonomic practice. This paper therefore explores the factors behind the success and failure of variety analysis technologies at the NIAB, in the process drawing upon the arguments made in favour of different techniques during the 1980s. Within these debates, social contingencies, including scientific values, research prestige, intellectual property concerns and commercial applications are evident. Such considerations continue in variety analysis today, with wider implications for conduct in agricultural science and policy: moreover, the technology harnessed in modern day variety analysis and classification often differs little from that of the 1980s. Electrophoresis continues in use for variety classification and analysis purposes in agriculture today.[7]

## 2. 'Outlook poor': funding agricultural research

The period around 1980 has been considered to mark the general faltering of generous state funding of the life sciences, as neoliberal economic policies associated with the Thatcher and Reagan governments introduced 'market forces' to public institutions.[8] British agricultural research during the 1980s was consequently viewed as faltering in lieu of government support. By the mid-twentieth century, British agricultural institutions were heavily dependent upon public funding, largely distributed through the Ministry for Agriculture, Fisheries and Food (MAFF) or the Agricultural Research Council (ARC). An overwhelming proportion of the budget of significant agricultural research centres, including the John Innes (JI) Institute and Plant Breeding Institute (PBI), came from state funds.[9] Reduction or withdrawal of government support directly affected these institutions' research programmes and technical work. In the case of the NIAB, financial pressure led to mechanized means of variety analysis being perceived in a mercantile light. Saving time and labour meant – or at least was perceived to mean – saving money.

A 1986 edition of *Nature* estimated that the UK budget for agricultural research would shrink by twenty-six percent between 1983 and 1991. Attempting to account for the government's 'beastly' budgetary behaviour towards the Agricultural and Food Research Council (AFRC, successor to the ARC), a contributor to the journal suggested that surplus commodities produced under the EEC's Common Agricultural Policy (CAP) and criticism of farmers' attitudes towards the environment were to blame.[10] Later issues of *Nature* carried equally pessimistic predictions on the future of British agricultural research. MAFF suffered cuts in its research budget throughout the decade, while the AFRC shed a quarter of its workforce from 1983 to 1988.[11] By the closing years of the 1980s, what were termed 'near-market research' programmes also came under fire.[12] Reductions in funding were so severe that mainstream British agricultural institutions became casualties. One high-profile loss was the Cambridge-based PBI. Following its closure, the majority of the Institute's researchers

[7]Robert J. Cooke, *Handbook of Variety Testing: Electrophoresis Testing* (Zurich: ISTA Works, 1992). Since the release of Cooke's original handbook, the International Seed Testing Association (ISTA) has held a number of meetings and workshops on electrophoresis: for instance a 2010 workshop on 'Species and Variety Testing / Protein electrophoresis' held in Hanover, Germany.

[8]Nicolas Rasmussen, *Gene Jockeys: Life Science and the Rise of Biotech Enterprise* (Baltimore: John Hopkins University Press, 2014), p. 3.

[9]Paolo Palladino, 'Science, technology and the economy: plant breeding in Great Britain, 1920-1970', *Economic History Review*, 49 (1996), 116–36 (124).

[10]'Downbeat plan for agriculture', *Nature* 320 (1986): 299. In earlier decades, the British government had similarly felt that basic research in agriculture did not translate into practical gains with enough frequency. See Jon Agar, 'Thatcher, scientist', *Notes and Records of the Royal Society of London*, 65 (2011), 215–32.

[11]Simon Hadlington, 'Outlook poor for agriculture', *Nature*, 332 (1988), 6.

[12]Christine McGourty, 'Erosion of UK research on agriculture and food must end', *Nature*, 337 (1989), 401.

relocated to the JI Institute and private plant breeding or biotech firms.[13] Despite its essential role in regulating new plant varieties produced by British breeders, the NIAB also suffered funding cuts throughout the decade.

By the time government cutbacks began to bite, the NIAB was already suffering from serious difficulties with workload and financial solvency. Britain's 1973 entry into the EEC was accompanied by a two-tier system of variety regulation: approved crop varieties would now be listed on both EEC National Lists – a list of approved crop plants produced by each member state – and the NIAB's existing Recommended Lists, bringing increased complexity and workloads to variety analysts.[14] With the introduction of full statutory seed certification in 1973, the British government became responsible for seeing EEC directives carried out. That same year MAFF negotiated a new contract with the NIAB, which directed the Institute to undertake scientific and technical work on behalf of the government.[15] This contract brought about dramatic changes in how the NIAB was funded. In the late 1960s, the NIAB possessed a largely independent income from farmers' fees and charged for its services, with direct payments from MAFF covering twelve percent of the Institute's expenditure. A decade later the situation had been reversed. MAFF payments for statutory EEC testing comprised sixty-eight percent of the NIAB's expenditure.[16] The late-twentieth century saw the NIAB move closer to government control and greater dependence on public funding, in line with other British agricultural organizations.

The impact of the EEC transition in variety regulation was still evident in the NIAB's activities during the early 1980s. The Official Seed Testing Station of England and Wales (OSTS) – a body charged with ensuring seed quality, nominally directed by the MAFF but operating under the auspices of the NIAB – had come under the greatest pressure as a result of European membership. By 1980 MAFF had informed the NIAB council that only seed testing services specifically required by legislation or international trade regulation would be commissioned. Yet in the spirit of the age, plans were simultaneously made for a concentration and reduction of the OSTS Cambridge laboratories, as seed certification tests were outsourced to satellite stations elsewhere.[17] Further MAFF meetings saw attempts to reduce the number of publicly-funded crop trials – the field testing of new crop varieties – in favour of those conducted under private contracts.[18] General cuts across government departments were passed directly on to NIAB. Correspondence with MAFF reveals that a two and a half percent reduction in manpower costs imposed on the Ministry would also apply to the NIAB in the 1980 to 1981 financial year.[19] The NIAB faced a crisis on two fronts: the heavy workload demanded by EEC regulation and reductions in MAFF funds which had become foundational to the everyday work of the Institute.

An alarming restriction of public funding for agricultural science did not seem an ideal situation in which the NIAB could begin its transition from technical to research work. Nor was the Institute particularly well equipped or orientated within the British agricultural research system for such a move. Yet the funding restrictions posed by government during the 1980s contained their own incentives for efficiency savings. Automated laboratory machinery could provide such savings, whether through more efficient processing of crop varieties or elimination of manpower. At the increasingly commercialized NIAB, the allure of laboratory machinery proved irresistible. Trends in wider biological work suggested that such machinery would quickly find practical, perhaps even lucrative, uses. In the early years of molecular biology, 1960 Nobel Prize winner Donald Glaser

[13]Edward Dart, interview with author 02 April 2015. Edward Dart was employed as a research director in ICI Seeds (later Zeneca), a leading biotech company. Zeneca was one of the private firms which attempted to purchase the genetics arm of the PBI following the Institute's closure.

[14]Silvey and Wellington, *Crop and Seed Improvement*, p. 117.

[15]H.A. Doughty to P.S. Wellington, 11/09/1975, Box C-3, Paper no. 668, NIAB.

[16]P.S. Wellington, 'Director's notes for Fellows on the annual report and accounts for 1978', NIAB Fellow's Newsletter 76, July 1979, Folder N1-11, NIAB.

[17]'General developments in 1980', Sixty-first report and accounts 1980, NIAB.

[18]'Crop priorities', 26 Nov 1981, Box C-3, Council Paper No. 754, NIAB.

[19]'Manpower policy', 5 June 1980, Box C-3, Executive Committee Paper No. 734, NIAB.

had introduced devices such as the 'dumbwaiter' and 'Cyclops' into commercial firms for analysing cell cultures.[20] A move towards molecularization in the biological sciences, combined with new laboratory equipment, suggested a future without traditional variety analysis by eye. At the NIAB, this trend was announced to its staff as part of a 'modernization plan' involving 'computerization of data capture and reporting, the automation of chemical analysis techniques and the development of new chemical methods for varietal identification.'[21]

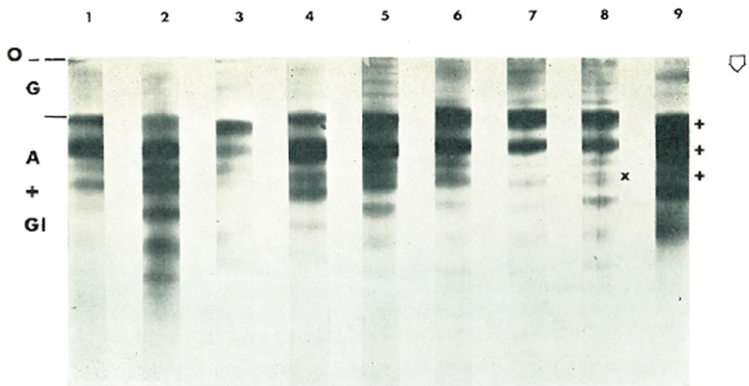
Despite the esteem and efficiency brought by new means of varietal classification and analysis, the NIAB struggled with funding shortfalls throughout the decade. A 1987 MAFF review of the Institute's statutory work announced significant falls in government funding to occur in 1992. Staff numbers were predicted to be further reduced, while the Institute was forced to focus its resources upon private variety testing contracts (VARTEST) and other 'sponsored research'.[22] By the later years of the 1980s, the NIAB's own 'near-market-research', including Recommended List work, had government support removed following the Barnes Review.[23] Yet the Institute continued with its modernization programme. In 1988 the NIAB took on a new Computer Unit, complete with analyst, programming and operating staff. Elsewhere in the Institute, everything from glasshouses to field trials experienced automation through computerization.[24] The 1980s ended as they had begun at NIAB: with calls for automation to counter MAFF cuts and speed up the Institute's alignment to the research and commercial sectors.

The 1980s brought numerous incentives for the NIAB to move towards biochemical research and laboratory machinery. The Institute required new markets to counter the scale of MAFF cuts, while improving the efficiency and accuracy of its variety identification and testing. Advances in molecular biology and biotechnology implied that future agricultural research would need to be conducted on the micro-level, with future analysis of genetically-altered crops another factor to consider. Yet significant obstacles, aside from financial pressure, could derail the NIAB's research programmes. Research-focused departments in the Institute, namely the Pathology and Chemical and Quality Assessment (C&QA) branches, traditionally held a lower status than the crop trials and variety evaluation services. The latter were considered uppermost in the Institute's strict hierarchical departmental structure.[25] Significant competitors in agricultural research existed, including the JI Institute, Rothamsted Experimental Station and Cambridge University. Of all the taxonomic techniques to be discussed, electrophoresis proved NIAB's most successful venture, despite an uphill struggle from meagre beginnings.

## 3. 'Do the research': electrophoresis

In 1982 Robert J. Cooke, a young biochemist, arrived at NIAB's C&QA branch, fresh from a postdoctoral research fellowship at the University of East Anglia. Given a single assistant, he was confronted with two empty rooms, comprising his new 'laboratory'. Yet encouraged by the head of C&QA, fellow biochemist Simon Draper, Cooke focused his attention on applying biochemical techniques to the NIAB's traditional areas of strength, namely variety identification and testing. Earlier work on a method of protein fingerprinting carried out by researchers at the NIAB had created a standardized method of starch gel electrophoresis applicable to cereals.[26] Put simply, electrophoresis works thanks to the different electric charges held by proteins. If a prepared plant sample is placed in a gel and an electric current run through it, then proteins separate into a pattern. This pattern can

[20] Eric J. Vettel, *Biotech: The Countercultural Origins of an Industry* (Philadelphia: University of Pennsylvania Press, 2006), p. 188.
[21] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.
[22] 'The Need to Increase Income-Earning', Sixty-Ninth Report and Accounts 1988, NIAB.
[23] 'The Effect of Government Cuts on the Institute's Work', Sixty-Ninth Report and Accounts 1988, NIAB.
[24] 'Progress Report' Sixty-Ninth Report and Accounts 1988, NIAB.
[25] Cooke interview, 2015.
[26] Simon R. Draper and E.A. Craig, 'A Phenotypic Classification of Wheat Gliadin Electropherograms', *Journal of the National Institute of Agricultural Botany*, 15 (1981), 390–98. Other crops, including vegetables, were analysed by the C&QA team and found to be just as amenable to electrophoresis.




S1 proteins separated on 7½% acrylamide gel buffered pH 8·3. From left to right, 1 Kleiber, 2 Koga II, 3 Heines VII, 4 Janus, 5 Joss Cambier, 6 Maris Ranger, 7 Flevina, 8 Clarion, 9 Eno. O = origin and the arrow indicates the direction of migration, G = gliadin bands and A + Gl = albumin and globulin bands, × = double band present in Clarion but not the other varieties, and + = bands seen in Eno which differed in mobility to those seen in other varieties.

**Figure 1.** An early depiction of gel electrophoresis in the NIAB's journal. The 'bands' on the image indicate the presence of different proteins. Image from R.P Ellis, 'The Identification of Wheat Varieties by the Electrophoresis of Grain Proteins', *Journal of the National Institute of Agricultural Botany*, 12 (1971), 223–35.

identify a crop plant by indicating the proportion of different proteins present (see Figure 1). The NIAB rapidly established itself as a premier organization for agricultural electrophoresis during the 1980s. The Institute was well placed to make this move, drawing upon its established reputation for independent arbitration in crop variety disputes.

Electrophoresis was by no means a new biochemical technique. Nor was it initially intended for agricultural purposes. Historians of biology traditionally associate electrophoresis with Lewontin and Hubby's research into molecular evolution. Electrophoresis was deployed in this field to break a theoretical impasse in population genetics in the late 1960s.[27] Yet the technology has a much longer theoretical and experimental history in biochemistry.[28] The taxonomic implications of electrophoresis were recognized as early as the mid-twentieth century. Based on an address given to the Botanical Society of America in 1949, an article in *The Scientific Monthly* associated the presence of certain proteins in plant tissues with infection by plant viruses. This finding raised the possibility of empirical diagnosis of plant viruses by electrophoresis of diseased samples. Scarcely a year later and the possibility had become reality, as comparison of virus components in electrophoresis apparatus allowed for their accurate identification.[29] By the late 1950s, zoologists in the United States were harnessing electrophoresis to identify wildlife, repeating the mantra 'blood will tell'.[30]

[27]Richard C. Lewontin, 'Twenty-five years in genetics: electrophoresis in the development of evolutionary genetics: milestone or millstone?' *Genetics*, 128 (1991), 657–62; Roger Lewin, *Patterns in Evolutions: The New Molecular View* (New York: Scientific American Library, 1999), pp. 93–94.

[28]Lily E. Kay, 'Laboratory technology and biological knowledge: the Tiselius apparatus, 1930-1945', *History and Philosophy of the Life Sciences*, 10 (1988), 51–72; Frank W. Putman, Alpha-, beta-, gamma-globulin-Arne Tiselius and the advent of electrophoresis', *Perspectives in Biology and Medicine*, 36 (1993), 323–37; Howard Hsueh-Hao Chiang, 'The laboratory technology of discrete molecular separation: the historical development of gel electrophoresis and the material epistemology of biomolecular science', *Journal of the History of Biology*, 42 (2009), 495--527.

[29]Sam G. Wildman and James Bonner, 'The electrophoretic detection of plant virus proteins', *The Scientific Monthly*, 70 (1950), 347–51; S.J. Singer, J.G. Bald, S.G. Wildman and R.D. Owen, 'The detection and isolation of naturally occurring strains of tobacco mosaic virus by electrophoresis', *Science*, 114 (New Series) (1951), 463–65.

[30]Murray L. Johnson and Merrill J. Wicks, 'Serum protein-electrophoresis in mammals-taxonomic implications', *Systematic Zoology*, 8 (1959), 88–95 (88).

The NIAB's C&QA staff had therefore hit upon a fresh application for an old technology. The race was on to further develop electrophoresis for technical work in agriculture. Following a literature review, the NIAB's biochemists embarked on a campaign of publication and promotion of their work in electrophoresis. The NIAB's approach was subsequently described by Cooke as 'fairly aggressive' and even 'ruthless', aiming to 'do the research, get the results and publish as quickly as possible'. At the same time, other British organizations demonstrated less vigour in pursuing electrophoresis work, leaving the Institute with an open playing field. This was fortunate for the NIAB, considering the prestigious agricultural organizations the Institute routinely operated alongside. The NIAB was not a premier research organization, a fact staff from organizations such as the JI Institute and University of Cambridge apparently never failed to point out to Cooke.[31]

Electrophoresis possessed some significant advantages over morphological identification of crops by eye. Morphological analysis required crops to be grown in special 'control plots' and carefully observed over a long period of time.[32] Conducting detailed observation and measurement of maturing crop plants was a long and laborious process. Advocates of electrophoresis therefore argued that identification could be carried out much more quickly by analysing grain samples through electrophoresis apparatus rather than measuring mature plants.[33] The shortcomings of morphological analysis became readily apparent from the early 1970s, when warnings that additional staff and workspace would be required for the NIAB to cope with an expected influx of crop varieties following EEC membership appeared.[34] Following this predicted varietal influx, the NIAB was forced to hire more staff and plant more test plots: hardly a sustainable solution for an institution under financial pressure.[35] Electrophoresis provided a way out.

New technological developments in electrophoresis fortuitously encouraged the NIAB's new-found interest. By the end of 1982, a new analytical method, termed polyacrylamide gel electrophoresis (PAGE) had been successfully applied by the NIAB to barley varieties on the EEC National List of approved varieties.[36] This represented another significant breakthrough, as barley was an economically important crop, particularly for the British brewing industry. The successful use of an improved form of electrophoresis opened commercial possibilities on a European-wide scale. The NIAB's research standing also improved in collaboration with the International Seed Testing Association (ISTA), although electrophoresis methods developed at the NIAB did not become standard reference methods for ISTA until 1989. Cooke gave a keynote address to the International Electrophoresis Society meeting in London in 1986, and published a chapter in 'Advances in Electrophoresis' in 1988. Promotion in scientific circles enhanced the NIAB's reputation outside the Institute's usual constituency of plant breeders, seed traders and farmers.[37] Commercial gains also came from the new technology, at a time when the Institute's financial stability was in serious doubt.

A lucrative service provided by the C&QA branch, electrophoresis was a welcome success story in hard times. The NIAB's director Graham Milbourn declared in 1987 that great demand existed for laboratory tests in both the Plant Pathology and C&QA branches.[38] Yet a greater impetus to electrophoresis research may have been provided by an association of automated machinery with efficiency savings, as described in the Institute's modernization plan. In this sense, the MAFF's financial crackdown may have inadvertently aided the NIAB's electrophoresis programme. The Institute sought to appeal to an array of audiences and markets with its biochemical

[31]Cooke interview, 2015.
[32]Kelly and Bowring, 'The development of seed certification', 149.
[33]R.P. Ellis, 'The Identification of Wheat Varieties by the Electrophoresis of Grain Proteins', *Journal of the National Institute of Agricultural Botany*, 12 (1971), 223–35 (233).
[34]'Additional Resources Required for Implementing EEC Directives on Marketing of Seed', October 1971, Box E-3, Executive Committee Paper No. 380, NIAB.
[35]Kelly and Bowring, 'The development of seed certification', 148.
[36]Quarterly Report to Council, June to August 1982, Document No. 763, Box C-3, NIAB.
[37]Cooke interview 2015.
[38]Graham Milbourn, 'Income-earning', Sixty-eighth report and accounts 1987, NIAB.

research. These included domestic growers, international bodies and foreign agricultural science institutions. Electrophoresis was certainly successful on the transnational scale. As a leading centre in the application of electrophoresis to crop identification, the NIAB received visitors from overseas, trained several people in the use of electrophoresis and was invited to participate in a series of development projects with the Division of Seed Technology in New Delhi, as a technical and scientific consultant.[39] Closer to home, Draper visited the Bundessortenamt (essentially the German equivalent of the NIAB) in 1982 to discuss electrophoresis and its possible 'DUS' applications ('DUS' refers to the criteria of diversity, uniformity and stability by which varieties could enter National or Recommended lists).[40] Cooke later mused that the readiness of overseas partners to work with the NIAB may have been in part due to the Institute's lower research status among British agricultural science institutions.[41] In other words, the NIAB was seen as more approachable and practically-orientated.

An obsession with new laboratory machinery permeated the NIAB's publications throughout the 1980s. In the process, the efficiency of biochemical methods of crop identification was favourably contrasted against established practices in agricultural botany. A charged narrative of scientific (and hence economic) triumph through biochemistry and technology emerged. By the mid-1980s, an outside observer might suppose that the botanically-trained eye of the NIAB field officer had been replaced by the new field of chemotaxonomy. The Institute's 1982 report represented the transition through the visual medium. Photographs of laboratory equipment rested alongside those of wheat fields, with electrophoresis favourably compared to traditional botanical techniques of identification.[42] New levels of standardization were also achievable through automated biochemistry. In 1982, the C&QA branch was asked by the Intervention Board for Agricultural Produce to act as an independent reference laboratory for cases requiring electrophoresis analysis to settle arbitration.[43] By the mid-1980s, the NIAB found itself actively involved with the European Brewery Convention and ISTA to decide on a standard reference method for the identification of wheat and barley varieties by electrophoresis.[44] Electrophoresis came to represent efficiency, modernity and reliability.

As the 1980s wore on, demand for electrophoresis only increased. In 1986 the C&QA branch conducted 13,512 'separations' on individual grains, a figure which rose to 28,986 by 1987.[45] Molecularization and mechanization were interlocking movements, growing in importance for the biological sciences and agriculture throughout the 1980s. Plant pathology, a major concern of NIAB, focused upon the molecular level during the same period.[46] Molecular biologists also approached plant breeders during the 1980s, although the former's early attempts at variety production fared poorly in the eyes of British breeders.[47] Advances in biotechnology and molecular-level examination implied new and additional forms of work for the NIAB's analysts. Electrophoresis was simultaneously part of a move towards molecularization and a reaction to its approach. Historians have called for an understanding of the 'molecularization movement' that extends beyond the confines of DNA and nucleic acids.[48] When this new history is applied to agriculture, techniques such as electrophoresis will play a far more significant role.

[39]Cooke interview, 2015.
[40]Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[41]Cooke interview, 2015.
[42]Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[43]Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.
[44]'Chemotaxonomy', Sixty-sixth report and accounts 1985, NIAB.
[45]'Workload', Sixty-Eighth Report and Accounts 1987, NIAB.
[46]R. Steven Turner, 'Potato agriculture, late blight science, and the molecularization of plant pathology', *Historical Studies in the Natural Sciences*, 38 (2008), 223–57.
[47]Andrew Webster, 'The incorporation of biotechnology into plant-breeding in Cambridge', in *Deciphering Science and Technology: The Social Relations of Expertise*, ed. by Ian Varcoe, Maureen McNeil and Steven Yearly (London: Macmillan, 1990), pp. 177--201 (p. 189).
[48]Lily E. Kay, 'Biochemists and molecular biologists: laboratories, networks, disciplines: comments', *Journal of the History of Biology*, 29 (1996), 447–50; Steven Turner, 'Potato agriculture', 235.

## 4. 'Modern methods': near-infrared spectroscopy

The triumphal narrative of electrophoresis at NIAB ultimately rests on firm foundations as numerous and successful applications of electrophoresis were made throughout the 1980s. Yet contrary to the straightforward account of its advocates, the story of late twentieth-century taxonomic methods does not begin and end with protein fingerprinting. Under the umbrella term of chemotaxonomy, other potential methods of variety identification were investigated by the NIAB's C&QA branch. Although electrophoresis remained the NIAB's flagship variety identification technology for much of the 1980s, various forms of spectroscopy and chromatography were trialled by the Institute throughout the 1980s. Investment in a variety of labour-saving technology appeared to be a sound decision, in the wake of revelations from the MAFF that requirements for government departments to reduce manpower costs would apply to the NIAB. Collaboration with European testing stations was also sought by the Institute as different laboratories developed separate techniques in taxonomy.[49]

New variety analysis technologies included near-infrared spectroscopy (NIRS) – for analysing crop constituents – and various forms of chromatography. From the early 1980s, the application of NIRS technology to variety analysis became a reality, albeit in an initially limited sphere. NIRS bombards samples with infrared radiation, to identify specific molecules via the presence of particular bonds or atoms and their place on a resulting spectrum. NIRS is extremely versatile and can be applied to a wide range of samples, including organic materials.[50] Analysis with NIRS can therefore provide valuable information about the molecular make-up of a crop plant, for instance its carbohydrate content or nutritional quality.

NIRS methods had been developed for use on grasses and forage crops by 1982. In the same year, the NIAB obtained vital calibration equations for the application of NIRS to the nitrogen and carbohydrate content of these crops. Rapid development of NIRS techniques at the NIAB was made possible through close ties with the Scottish Crop Research Institute, which possessed its own NIRS instrument. NIAB staff, including Simon Draper, arranged multiple visits to their Scottish counterpart.[51] Yet calibration work and the application of new equations did not result in quick results. It was expected that the application of NIRS equations to nitrogen and water-soluble carbohydrate content would take up to a year. In the meantime, special plant samples for NIRS analysis were obtained from test plots at the NIAB's headquarters in Cambridge.[52]

Despite ongoing advances in the use of electrophoresis and NIRS, other methods of variety analysis were also tested at NIAB during the 1980s. The Institute's 1986 annual report declared that the C&QA branch had made new advances in the 'automation' of chromatography, via an automatic injection system and data capture facility, capable of carrying out unattended analytical techniques overnight, to the benefit of 'cost-effectiveness' and 'improved efficiency' (see Figure 2).[53] Draper considered chromatography to possess potential for variety identification, although this would not be fully realized until the late 1980s.[54] The relative unimportance of chromatography in comparison to electrophoresis at NIAB can be explained through developmental speed. By the time chromatography featured in the day-to-day running of the Institute, electrophoresis was an established and successful method. Yet the same explanation cannot be given for NIRS, which emerged in tandem with the electrophoresis programme.

Different forms of variety analysis technology emerged at NIAB to occupy various niches. Measuring the moisture content of cereals (which determines the storage life of seeds) was one example of a practice where new approaches were in demand. Moisture measurement had

[49]Quarterly Report to Council, September to October 1982, Box C-3, Document No. 766, NIAB.

[50]Yakov M. Rabkin, 'Technological innovation in science: the adoption of infrared spectroscopy by chemists', *Isis*, 78 (1987), 31–54 (31).

[51]Quarterly Report to Council, March-May 1982, Box C-3, Document No. 761, NIAB.

[52]Quarterly Report to Council, June to August 1982, Box C-3, Document No. 763, NIAB.

[53]'Chemistry and quality assessment branch', Sixty-seventh report and accounts 1986, NIAB. This 'automation' involved glucosinolate analysis of oilseed rape by high performance liquid chromatography (HPLC).

[54]'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.

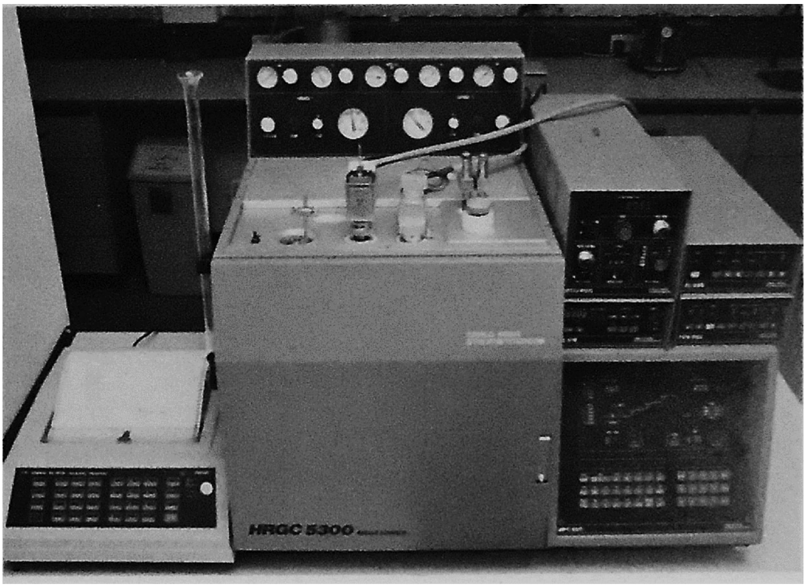



**Figure 2.** A HRGC 5300 gas chromatograph at the NIAB. The Institute invested in new laboratory equipment throughout the 1980s, seeking more efficient methods of analysing and classifying crop plants. Image from 'NIAB and the environment', Annual Report 1990, NIAB.

traditionally been conducted by oven-drying cereals, a time-consuming and expensive process. Alternative methods, including NIRS and commercial moisture meters were introduced during the early 1980s. Yet an empty 'technological niche' was provided by the desire to measure intact, rather than milled, grain: a task NIRS analysis struggled to achieve. In 1984 a NIAB research team instead suggested the use of nuclear magnetic resonance (NMR) instruments.[55] The range of work conducted at the NIAB allowed multiple research programmes to flourish. Moreover, the workload demanded by the Institute's various activities drove these research programmes in the direction of efficiency and automation.

Although NIRS has been overshadowed by the success of electrophoresis in agricultural botany, the technique cannot be dismissed as a failed innovation. In fact, multiple technologies aimed at variety analysis operated concurrently in the NIAB's laboratories during the 1980s. This was made possible by applying different technological methods to different aspects of variety analysis. Analytical work on potatoes during 1982 saw electrophoresis used for standard variety identification, while NIRS analysed the contents of potato varieties. Both methods were considered successful. Staff input to analysis work remained at a minimum, despite an influx of new varieties for testing from 1977 to 1982. 'Substantial benefit' was therefore seen to have resulted from new methods and experimental design, keeping manpower costs low at a time of government austerity.[56] Chemical analysis conducted through NIRS, when combined with variety identification via electrophoresis, created an efficient system for dealing with new crop varieties.

The rationale behind the introduction of 'modern methods of [variety] analysis' at the Institute was summarized in 1982 as meeting growers' requirements for additional information on the nutritional quality of breeders' varieties, while overcoming 'current economic pressures for cost-effective methods'.[57] NIRS and electrophoresis were introduced during a similar timeframe at the NIAB to

[55] J.H. Morley, P.D. Fletcher and A.G. Morgan, 'The estimation of moisture in whole grain wheat and barley using nuclear magnetic resonance spectroscopy', *Journal of the National Institute of Agricultural Botany*, 16 (1984), 437–42 (437).
[56] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.
[57] 'Changes in the work of chemistry and quality assessment branch 1977-82', Sixty-third report and accounts 1982, NIAB.

counter financial pressures and increasing demand from industry. Both programmes allowed the Institute to expand its research work and interact with other prestigious agricultural research institutions. Yet infrared spectroscopy was a tried-and-tested technology by the time of its uptake by the NIAB, just as electrophoresis was similarly a decades-old method of analysis in the biological sciences. Due to falling equipment costs and a relatively low level of expertise required to operate the machinery, infrared spectroscopy had become a routine tool in organic and inorganic chemistry by the 1960s.[58] Industrial applications had begun even earlier, with fuel companies utilizing spectroscopy for 'fingerprinting' compounds from the late 1930s.[59]

The NIAB saw significant financial returns and savings from NIRS, electrophoresis and other variety analysis techniques. By 1985 the Institute had announced the launch of a five-year development plan, aimed at countering stringent government cuts. The role of new techniques in variety analysis was plainly laid out. Resources were allocated for 'automation and modernization', which included 'the automation of chemical analysis techniques and the development of new chemical methods for variety identification'.[60] Multiple techniques of automated analysis were investigated by the NIAB's researchers during the 1980s under the banner of 'modernity'. This policy was justified in 1986 as broadening the base of the Institute's income by increasing the volume of contract work staff could undertake.[61] The attempt to modernize crop classification and analysis techniques was a repercussion of the NIAB's search for new sources of funding in the wake of government cuts. The widespread and rapid nature of the Institute's research into varietal analysis were symptomatic of this search.

Two points of interest emerge from the Institute's development of varietal analysis programmes. Firstly, existing technology was adopted from other fields in biology or biochemistry for use in agricultural botany. Methods of electrophoresis and spectroscopy were then presented as cutting-edge and a force for modernization within the NIAB and the wider agricultural community, regardless of their actual age. Secondly, NIRS and electrophoresis were ultimately able to operate alongside each other, in what was fast becoming a crowded field, as each was directed towards a different aspects of variety analysis: electrophoresis to classification, NIRS to obtaining information on crop quality. Yet the final example discussed in this paper directly competed with electrophoresis in the sphere of crop classification. The arguments made in favour of machine vision systems at the NIAB demonstrate how taxonomic technology was shaped by a combination of scientific, commercial and intellectual property considerations.

## 5. 'Scientific objectivity': machine vision systems

A 1988 article in the NIAB's journal described an unusual device assembled at the Institute by Simon Draper and P.D. Keefe, the latter a member of the OSTS. The pair created a custom-built 'image analysis facility', designed to measure the size and shape of plant samples submitted to the NIAB (see Figure 3).[62] The prototype device consisted of a motorized camera gantry and image analysis computer, loaded with measurement software. By comparing quantitative data on samples collected by the camera with an existing database, the system could potentially classify varieties based on machine-generated observations of their morphology. For historians of science and technology, the term 'machine vision' brings to mind attempts to mechanically reproduce scientific images during the early-twentieth century. Mechanical objectivity had then involved the use of new image technologies, supplemented by new scientific attitudes. Yet scientists ultimately despaired

[58] Rabkin, 'Technological innovation', 32.
[59] Rabkin, 'Technological innovation', 40.
[60] 'Future developments', Sixty-sixth report and accounts 1985, NIAB.
[61] 'Future developments', Sixty-sixth report and accounts 1985, NIAB.
[62] P.D. Keefe and Simon R. Draper, 'An automated machine vision system for the morphometry of new cultivars and plant genebank accessions', *Plant Varieties and Seeds*, 1 (1988), 1–11 (1). *Plant Varieties and Seeds* was the new title given to the *Journal of the National Institute of Agricultural Botany*.

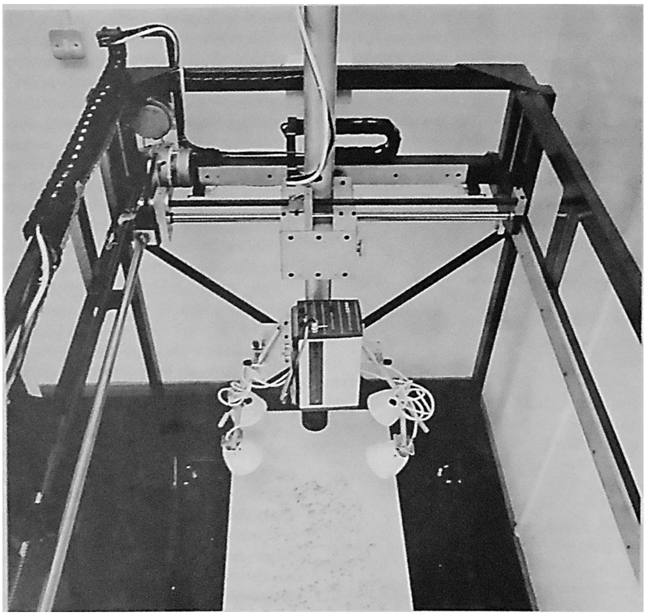


**Figure 3.** A prototype machine vision system, produced by staff at the NIAB and OSTS in 1988. New machine vision systems were developed and tested at the Institute throughout the 1990s. Image from P.D. Keefe and Simon R. Draper, 'An automated machine vision system for the morphometry of new cultivars and plant genebank accessions', *Plant Varieties and Seeds*, 1 (1988), 1–11.

of extirpating subjectivity, whilst others sought objectivity in mathematics and logic, rather than images.[63] The existence of a modern machine vision system at NIAB during the 1980s possesses points of interest for both the history of scientific objectivity and the socio-economic influences behind the selection of taxonomic technology.

For its advocates, machine vision offered a means of eliminating the subjectivity associated with individual scientific practitioners. Describing the benefits of their machine, Draper and Keefe explained that physical traits of seeds and cuttings which had previously been subjectively measured by eye could now be objectively recorded by machines. In fact, human input could be avoided altogether once their automated machine vision system was up and running. The devices would introduce savings of staff time and effort, automatism avoiding errors arising from operator fatigue.[64] It is clear that bypassing human operators possessed potential economic benefits for the NIAB, lessening staff workload or cutting the Institute's workforce. Scientific objectivity and efficiency savings were not necessarily incompatible. During the 1970s, the OSTS had struggled under an increased workload, partly as the consequence of new regulations following Britain's entry into the EEC. While the OSTS was subject to the same financial pressures as other departments at the NIAB, the role of the former's field officers had always been made notoriously difficult by the range of expertise required of them. Candidates had to possess a thorough grasp of the demands of farmers and potential input of breeders and seed merchants, while simultaneously keeping abreast of scientific progress in a number of relevant disciplines.[65] Meeting breeders' demand for rapid variety identification while maintaining high scientific standards presented the NIAB's officers with a formidable challenge.

The machine vision system represented an interaction between members of the NIAB's disparate branches, which Cooke had considered separated by institutional cultures and a strict hierarchy.[66]

[63]Lorraine Daston and Peter Galison, *Objectivity* (New York: Zone Books, 2010), pp. 115–90.
[64]Keefe and Draper, 'An automated machine vision system', 8.
[65]Rosemary Sells, *From Seedtime to Harvest: The Life of Frank Horne 1904–1975* (Cambridge: Hobson's Press, 1978), p. 105.
[66]Cooke interview, 2015.

Much of the OSTS's struggle to meet demand during the 1970s was due to the increasingly complex nature of disease-resistance testing. As the NIAB's Plant Pathology and C&QA branches embraced new research programmes, the Institute's variety analysts followed the modernization and automation drive seen in other branches. Machine vision was initially justified in much the same language as electrophoresis, an unsurprising coincidence given that Draper was heavily involved in both research programmes. A common purpose in developing the machine vision system came from outside the NIAB. Both Keefe and Draper perceived their machine vision system as dealing with high, unmet demand for variety analysis. Despite the NIAB's successful electrophoresis programme, examination of morphological characteristics remained necessary for field certification on the international level. Bodies such as the International Board for Genetic Resources (IBPGR) continued to issue standardized morphological descriptions for crop species throughout the 1980s. Unlike electrophoresis, machine vision could mechanize and streamline identification, while complying with the morphological descriptions required by regulatory bodies.[67]

Investigations into the practicability of machine vision systems and image analysis technology were not confined to Cambridge. The NIAB's 1989 journal carried an article by two Perth-based engineers, describing a preliminary study on the application of 'pattern recognition techniques' to Australian wheat.[68] Visual identification of Australian wheat was difficult, as there was little genetic difference between cultivars. While gel electrophoresis was successful, facilities and techniques were not as highly developed in Western Australia. Preparation time was substantial and samples could only be analysed in specialist laboratories by experienced personnel. Digital image processing, with a proven track record in robotics and industrial inspection, had the advantages of being easily deployed, non-destructive to samples and providing inexpensive, real-time analysis. Yet by this time only the 'broad structural properties' of grains were subject to analysis, with finer details beyond the capabilities of existing technology.[69] The interest of Australian engineers in the NIAB's machine vision work reveals that the technology attracted diverse audiences, possessing significant advantages over its competitors in certain contexts. Furthermore, machine vision was promising enough to combine engineering and biological interests, in the same manner as biotechnology spans both fields.[70]

In a 1989 paper, Draper and Keefe favourably compared machine vision with biochemical methods – including electrophoresis – in a similar manner to their Australian counterparts. Apart from its alignment with existing national guidelines, machine vision was quick and inexpensive. Cameras and databases could potentially penetrate new markets, where electrophoresis had failed. Cultivar registration by organizations such as ISTA had proven largely resistant to PAGE electrophoresis, despite standardized electrophoresis methods laid out by that association in 1986.[71] Breeders also objected to electrophoresis and similar technologies because they feared 'biochemical piracy'.[72] Electrophoretic methods and charts could be open to manipulation by unscrupulous breeders. An alteration or tweak of an electrophoresis experiment could therefore see a variety produced which appeared dissimilar from existing types based on an electrophoresis chart, but was in reality phenotypically identical to an existing crop variety.[73] In other words, traditional morphological identification made sense from a legal and commercial standpoint.

Yet changes to the practice of varietal identification and analysis could only occur in concert with other developments. Accounts of computerization for data management purposes first emerged at

[67]Keefe and Draper, 'An automated machine vision system', 1–2.

[68]D.G. Myers and K.J. Edsall, 'The application of image processing techniques to the identification of Australian wheat varieties' *Plant Varieties and Seeds*, 2 (1989), 109–16 (109).

[69]Myers and Edsall, 'The application of image processing', 110.

[70]Robert Bud, 'Biotechnology in the twentieth century', *Social Studies of Science*, 21 (1991), 415–57 (418–19).

[71]NIAB developed a standard method of PAGE electrophoresis which was approved by the ISTA for wheat and barley in 1986. In the same year, the European Business Council (EBC) approved electrophoresis for barley only. 'Electrophoresis', Sixty-seventh report and accounts 1986, NIAB.

[72]Simon R. Draper and P.D. Keefe, 'Machine vision for the characterization and identification of cultivars', *Plant Varieties and Seeds*, 2 (1989), 53–62 (53--54).

[73]This fear of variety theft or fraud was articulated to the author at the NIAB Seminar, 09 February 2016.

the NIAB around the mid-1970s.[74] Yet an early attempt to computerize cereal identification and analysis in voluntary schemes at the NIAB collapsed under the number of options and flexibility required of it.[75] By the mid-1980s, the arrival of microcomputers at the Institute had improved basic work in the NIAB's Seed Handling Unit, including label printing and record keeping.[76] Elsewhere in the biological sciences, computerization played a more sophisticated role in the development of, for example, protein sequencing from the 1950s.[77] Yet computing power and sophistication remained inadequate for machine vision systems. Machine vision came with technical challenges which persisted well into the 1990s. Creating computer programs capable of interpreting complex, natural structures remained a major obstacle in further development of the technology.[78]

Despite breeders' protests against electrophoresis and other biochemical methods of varietal analysis, machine vision was slow to develop beyond the prototype stage at the NIAB. By the late 1980s, the Institute may have had far too much invested in the C&QA branch's lucrative and long-standing electrophoresis programme and other techniques in chemotaxonomy to fully embrace machine vision systems. Furthermore, if crop variability could not be accurately interpreted by existing computers, applying machine vision to high-volume variety identification systems would clearly be problematic. Multiple 'high-tech' solutions were deployed in NIAB's variety analysis work during the 1980s, with the ultimate aim of securing the Institute's finances. Their success depended upon technological viability, commercial applicability and conforming to existing values in contemporary scientific and legal systems.

## 6. Conclusion

This paper has demonstrated that the development and uptake of taxonomic techniques at the NIAB during the 1980s was heavily reliant upon social contingencies. New methods of crop classification and analysis were investigated by the Institute in response to economic pressures, as more crop varieties were submitted to the NIAB at the same time as government cutbacks to agricultural institutions began to bite. When it came to deciding between different technologies, a myriad of factors came into consideration: speed, cost, objectivity and intellectual property rights. At the NIAB, technologies also existed side by side, either working on different aspects of crop analysis or deployed in different contexts. Crop classification at the Institute during the 1980s also offers two points of further interest to the historian: firstly, as an example of the application of 'vintage' technology in action, and secondly as a demonstration that twentieth-century crop taxonomic techniques did not inevitably follow the path of molecularization.

Nicholas Jardine has noted that it takes a great deal of work for scientists to finish off old questions and theories: so much so, that what we might expect to be obsolete or outdated ideas can form an integral part of science. Moreover, our telling of intellectual history tends not to move at the 'textbook level', leaving historians ignorant of what ideas and practices were commonplace at a given time.[79] 'Vintage' ideas and practices can therefore successfully operate within certain fields. Historian of technology David Edgerton also argues that technologies of varying vintages can similarly occupy the same institutional space: in other words, the old can happily exist alongside the new.[80] Vintage technologies can persist in fields such as agricultural botany for longer than we might expect,

[74]H.D. Patterson and M. Talbot, 'A computing system for cereal variety trials', *The Journal of the National Institute of Agricultural Botany*, 13 (1974), 142–51.
[75]Silvey and Wellington, *Crop and Seed Improvement*, p. 133.
[76]'Seed handling unit', Sixty-seventh report and accounts 1986, NIAB.
[77]Bruno J. Strasser, 'Collecting, comparing, and computing sequences: the making of Margaret O. Dayhoff's *Atlas of Protein Sequence and Structure*, 1954-1965', *Journal of the History of Biology*, 43 (2010), 623–60.
[78]C.J. Taylor, T.F. Cootes, A. Lanitis, G. Edwards, P. Smyth and A.C.W. Kotcheff, 'Model-Based Interpretation of Complex and Variable Images', *Philosophical Transactions: Biological Sciences*, 352 (1997), 1267--74.
[79]Gregory Radick, 'The Studies C interview: Nicholas Jardine' *Studies in the History and Philosophy of Biological and Biomedical Sciences*, 43 (2012), I–III (II).
[80]David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (London: Profile, 2006).

fulfilling specific social contingencies. At the NIAB, the move from morphological analysis to molecular techniques was portrayed as a process of modernization. Yet electrophoresis and spectroscopy were long-established techniques in biochemistry by the 1980s. Their use at the NIAB therefore represents a successful uptake and application of vintage technologies in a new context.

Moreover, molecular techniques like electrophoresis and spectroscopy did not immediately replace traditional methods of recording morphological characteristics of crops by eye at the NIAB. A 1985 article in the Institute's journal listed morphological characteristics used to differentiate hybrid wheat-rye from bread wheat. Visual representations of these characteristics were included to aid readers.[81] Botanical expertise persisted as a relevant technical practice at the Institute. Although there was some initial hostility from traditional 'technical' branches within the NIAB, physiology and biochemistry ultimately ended up covering different aspects of plant science.[82] It was not problems with morphological analysis, but external pressure from trading standards and industrial demands for more information on crop quality which forced the NIAB to reconsider its existing methods.[83] Ultimately, multiple taxonomic practices, old and new, existed side by side within the Institute during the 1980s and beyond.

Neither was the move towards the molecular techniques at the NIAB uncontested or inevitable. Elsewhere in the biological sciences, molecularization was consciously chosen and pursued: the adoption of molecular techniques 'represented no natural or inevitable path for biological research'.[84] Within the NIAB, morphological analysis was not simply replaced by electrophoresis or NIRS. Instead, molecular techniques were adopted by the Institute for pragmatic reasons of economy and efficiency. As the testing of machine vision systems shows, the NIAB did not blindly follow the path of molecularization. During the 1990s, ever more advanced machine vision systems were created and tested by the Institute's Image Analysis Group.[85] Image analysis now plays an important role in variety classification at the NIAB.[86]

Even as Cooke, Draper and others conducted their research and promotion of electrophoresis, NIRS and machine vision systems, new methods of crop classification and analysis were emerging. A 1989 article in the NIAB's journal described yet another means of varietal identification: DNA probes. Its authors hit upon a number of themes which had occupied the NIAB, including the need to reliably and rapidly screen an ever-expanding number of crop varieties following the introduction of plant variety rights and the 'need to protect genotypes'.[87] Electrophoresis was fast approaching its technical limits — varieties would eventually become indistinguishable as breeders selected for key protein types. With improvements in molecular biology, 'variation at the DNA level' could now be detected.[88] The NIAB's researchers were aware of advances in DNA sequencing and its implication for electrophoresis. Yet other developments in DNA-level technology also concerned them, namely recombinant DNA technology, which was finally coming to fruition after years of promise.[89]

This paper has provided an account of taxonomic practice in late-twentieth century agricultural botany. It has described the development of three taxonomic technologies at the NIAB during the 1980s, linking the need for new methods in variety analysis to falls in government funding and available manpower. Electrophoresis and NIRS were also linked to an institutional rhetoric citing the

[81] I.E. Wilson and A.J. Eade, 'Preliminary assessment of some morphological characters in Triticale for use in varietal description', *The Journal of the National Institute of Agricultural Botany*, 17 (1985), 41–52.
[82] Cooke interview 2015.
[83] 'Cereals', Sixty-seventh report and accounts 1986, NIAB.
[84] Lily E. Kay, *The Molecular Vision of Life: Caltech, the Rockefeller Foundation, and the Rise of the New Biology* (Stanford: Stanford University Press, 1993); Steven Turner, 'Potato agriculture', 255.
[85] D.E. Warren, 'Image analysis research at NIAB: chrysanthemum leaf shape', *Plant Varieties and Seeds*, 10 (1997), 59–61.
[86] Discussion following the NIAB Seminar, 09 February 2016.
[87] C.C. Ainsworth and P.J. Sharp, 'The potential role of DNA probes in plant variety identification', *Plant Varieties and Seeds*, 2 (1989), 27–34 (27).
[88] Ainsworth and Sharp, 'The potential role of DNA probes', 28.
[89] Cooke interview, 2015.

benefits of modernity and automation. Machine vision systems were justified on wider grounds, including improvements in scientific objectivity and dealing with the intellectual property concerns of plant breeders. The adoption of molecular crop classification and analysis techniques at the NIAB was by no means a straightforward or inevitable process. The 1980s had been marked by a struggle for financial survival, resulting in dramatic shifts towards private funding sources and schemes to automate and computerize the Institute's work. To ensure its survival, the NIAB pursued diverse techniques in crop classification and analysis on the basis of practicality and utility. Molecularization at the NIAB was not a deterministic process but one driven by pragmatic responses to its changing circumstances.

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