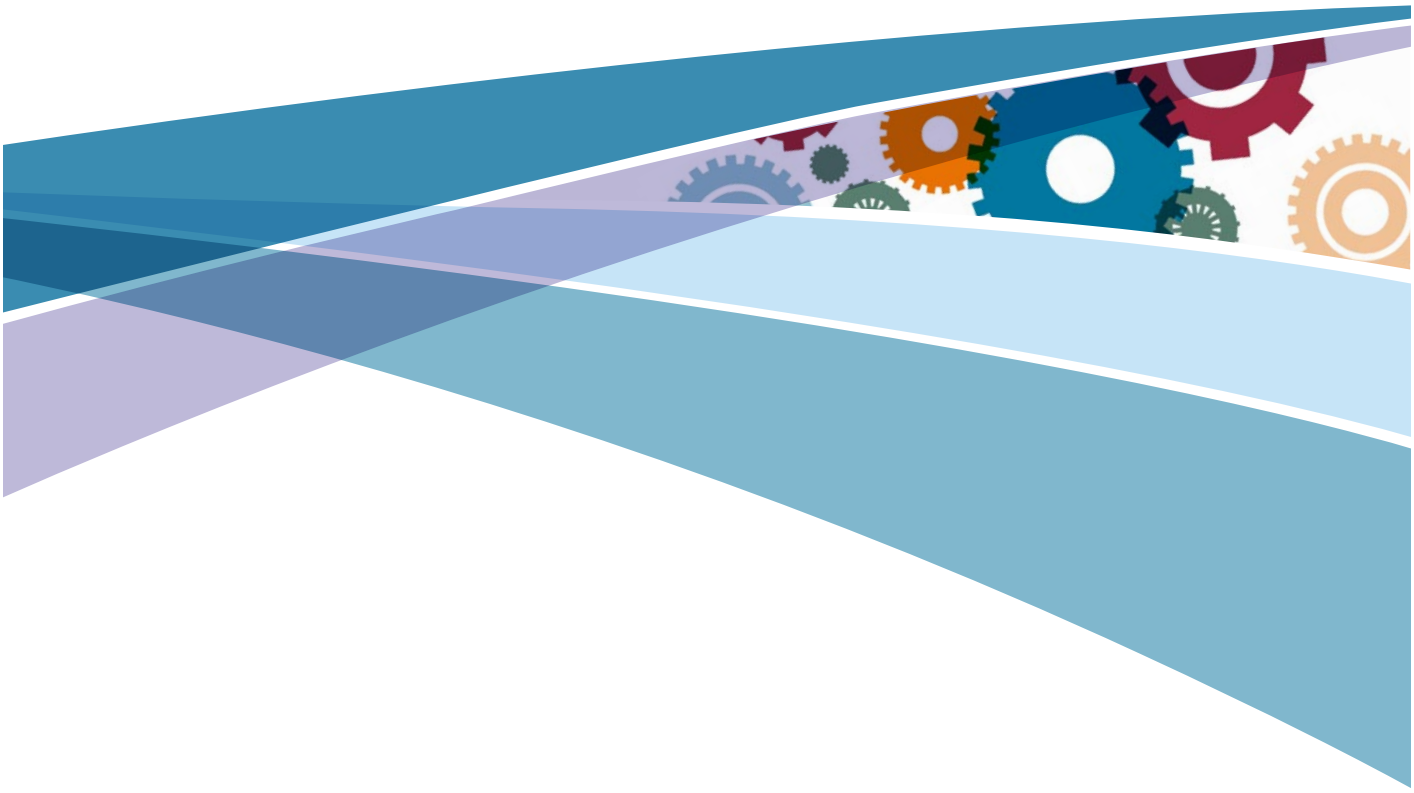
Intellectual Property Office

The UK Plant Breeding Sector and Innovation



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Contents

Executive Summary

This report was commissioned by the UK Intellectual Property Office with the aim of understanding both the structure and importance of UK plant breeding, as well as current innovation activity. Plant breeding is conducted by UK subsidiaries of transnational corporations (TNCs) and UK based businesses. Hence, for the purpose of this report, we define commercial UK plant breeding as: **'physical investment into research and development (R&D) activities based in the UK directed towards producing new commercial varieties of plants.'**

A small number of studies have attempted to understand plant breeding activity but there are very few up-to-date examinations focused on the UK. The key questions addressed by this report are to:

- identify the economic contribution of commercial plant breeding
- map the current structure of commercial plant breeding in the UK, along with the structural and economic barriers for conducting a plant breeding programme, and
- understand how innovation occurs within plant breeding, with reference to how intellectual property rights (IPRs) are currently used

In order to answer these questions secondary data from numerous sources were gathered and analysed. A questionnaire was administered to those conducting plant breeding programmes in the UK to understand investment levels, as well as perceptions towards conducting R&D in the UK.

The plant breeding sector serves agricultural, horticultural and ornamental markets. Breeders produce varieties for farmers, for vegetable and fruit growers, and nurseries. This latter sector is under represented in data available on the economic importance and structure of ornamental plants. In addition, the respondents to the survey were from agricultural and vegetable plant breeding interests. Although we identified larger breeders of ornamental plants for the UK market, no responses were obtained to understand this sector. Accordingly, ornamentals is under-represented within the findings of the report.

The economic contribution of commercial plant breeding in the UK

Using responses from two surveys, which covered agricultural and vegetable breeding companies, we estimate the annual turnover from UK plant breeding to be in the region of £200 to £230 million, with R&D expenditure estimated at around £30 to 40 million. This figure does not include capital spend which may be one-off expenditures such as greenhouses etc. In addition, we estimate just under 400 employees are directly employed in UK research and technical activities. Research activity for TNC's is co-ordinated across countries, and material and testing technologies are shared with parent companies. Though these are global leaders in plant breeding, their UK operations tend to be small (based solely on research staff employed and turnover) and only micro, small and medium size enterprises exist within commercial UK plant breeding.

The indirect benefit of genetic improvement from plant breeding is substantial through yield and quality improvements and increased resilience to changing climatic conditions. The food supply chain contributes 7% of gross value added to the UK economy (£109 billion) and most of this, whether crops or animals, is underpinned by plant breeding.

The UK market for seeds is relatively small, compared to France or Germany, and the UK is a net importer of seeds. The reliance on imports indicates that the UK benefits from genetic improvements from mainland Europe and from non-European countries. France, Germany and Switzerland are the main bases for agricultural and vegetable plant breeding, whereas the Netherlands is strong on ornamentals and potatoes. Non-EU countries, through TNCs such as Monsanto, will supply seeds for a range of markets, but are particularly dominant in oilseeds. Accordingly, whilst the institutional structure of UK plant breeding is important to UK growers, it may be that international systems of governance and non-UK innovation mechanisms will be significant in maintaining or improving performance for UK markets.

The structure of UK plant breeding

Around 11 companies can be identified who conduct a serious plant breeding programme in the UK. In addition, a further 12 companies were identified who conduct some form of plant breeding research for the agricultural and vegetable sectors. The ornamentals sector is highly fragmented but 13 larger breeders of ornamentals are currently active in the UK.

Agricultural and vegetable plant breeders are mostly subsidiaries of TNCs, though UK based companies exist serving the cereals, vegetables, legumes, grass and potato markets. The main countries with a strong plant breeding presence are mostly centrally based in mainland Europe. The EU mainland harbours global leaders such as KWS, Limagrain and Syngenta[1], who are part of the traditional ‘Big 6’ global plant breeders.

Plant breeding covers a range of techniques, but at the commercial end the practice of plant breeding is highly research intensive, requiring both staff and facilities to manage numerous lines of genetic material to produce marketable varieties. Accordingly, barriers to entry are high and breeding programmes are usually purchased as part of acquisitions within the seed breeding sector, rather than established. Nevertheless, some markets are served by smaller UK plant breeders. This may indicate that management of only a few lines and specialisation into a particular crop may offer entry into the market.

There are high levels of market concentration in plant breeding with usually three to four players dominant in agricultural and vegetable markets. Concentration ratios of the top four players within agricultural markets range from 58% of cumulative market share for the fodder and oilseeds sectors, to 95% of cumulative market share for barley sectors. Only the pulses market could be considered a competitive marketplace: wheat, fodder and oilseeds and potatoes are moderately concentrated; while barley and other cereals (comprising oats, triticale and rye) are probably the most concentrated sectors in UK plant breeding.

1 The Chinese State Owned China National Chemical Corporation (ChemChina) has recently made an offer to buy Syngenta for around $43 billion.

How innovation occurs within plant breeding

The business models of plant breeders revolve around applying and securing plant variety rights (PVRs)[2]. For a number of breeders this is the sole source of income and is needed to sustain research activity. Most companies will pursue protection at the EU level for the life of profitability of the variety. In addition, all of the breeders surveyed had applied for patents with one of the surveyed breeders owning three granted patents.

There are currently 1,249 PVRs in force for the UK. The ornamentals sector has the majority of PVRs in force, (835 or 66% of the total PVRs). Fruit and vegetable varieties have 219 PVRs (18%) with the remaining PVRs (15%) related to agricultural crops. There is less information held on patents by UK plant breeders, but of the breeders surveyed all were holders of patents or were in the process of applying for patents.

Commercial plant breeding is a research intensive activity and the average time for varietal development could be as low as six years but, in some cases, as high as 20 years. This includes identifying attractive traits and testing to gain access onto Recommended lists which should ensure adoption by growers. Research and development is highly risky given the high failure rate of lines to reach Recommended list status. The average commercial life for a successful wheat or barley variety is around five-six years. The most active sectors for varietal introduction are cereals, sugar beet and oilseeds, with around 12-15% of varieties on the National List introduced in the last year. The grasses, potatoes and ornamental sectors have the lowest level of new varietal development. The market for varieties appears to be highly competitive, with healthy replacement of market leaders occurring over sustained periods. Smaller UK breeders, such as Mike Pickford Seeds and Blackman Agriculture Limited do maintain a portion of the market.

Given the transnational structure and co-ordination of research across countries it is difficult to determine the amount of innovation occurring within the UK that leads directly to UK produced seed. Genetic material, the main input into plant breeding, is available for development and also supplied by the public sector. As an estimate, around 35 to 40% of third party material is used by UK plant breeders to develop new varieties. Most TNCs have cross-licensing agreements which licence material and technologies between different companies. This could lead to anti-competitive behaviour if licences are applied to commercially available material and so restricts access to breeding material.

The strong UK public R&D base in plant breeding may attract foreign direct investment and most companies surveyed engaged in public-private linkage initiatives as a means to share the cost and physical requirements for maintaining a plant breeding programme. However there are some barriers to greater public-private sector working related to ownership of intellectual property and the risks and costs of commercialising public sector research. In addition, where TNCs are involved, it is not clear how much of a spill-over effect occurs from UK funding initiatives to non-UK businesses.

2 Plant variety rights (PVR), are rights granted to the breeder of a new variety of plant that give the breeder exclusive control over the propagating material and harvested material of a new variety for a number of years.

Seed prices and farm saved seed

Though the contribution of seeds to overall farm input costs has remained relatively small and static,the price of seed has doubled in real terms since 2000. This may be due to concentration occurring within plant breeding over this time, but a significant factor will be the exchange rate affecting the cost of inputs at the farm level. A response to high seed prices could be to plant more farm saved seed (FSS). The amount of farm saved seed tends to vary from 35% to over 50% of total seeds planted with the amount tending to reflect the economic position of farmers. Similar rates of FSS occur across most EU countries, though administrative systems differ in terms of their adequacy for collecting FSS royalties.

FSS royalties contribute to around a third of the total income available to support UK breeding programmes. Clearly the reduced royalty from FSS could be a disincentive to innovate within plant breeding. However, plant breeders benefit from the organised royalty collection system in the UK and this may be an incentive to continue to invest, compared to countries where royalty collection systems are inadequate or newly established.

1.0. Introduction

This report was commissioned by the UK Intellectual Property Office with the aim of understanding both the economic importance and the current innovation activity of the commercial plant breeding sector in the UK. Plant breeding is a particularly dynamic and research intensive activity with long lag times between investment and returns, which emerge in the form of varietal seed stock with particular traits or characteristics that are attractive to UK cropping and horticultural producers.

There is limited publically available data on the commercial UK plant breeding sector, which is served by a small number of UK Limited companies and representatives of Transnational Corporations (TNC) who have invested in UK operations. Moreover, UK growers have access to seeds which emerge from UK based plant breeders, but also by commercially available varieties which have been developed in other EU and Non-EU regions. Consequently, there is limited current knowledge of the activity of UK based plant breeding and the levels of innovation in this industry.

The purpose of this project is to map current UK plant breeding activities, along with the innovation activity across a range of sub-sectors within agricultural and horticultural markets.

The aims of this report are to:

- identify the economic importance of commercial plant breeding
- map the current structure of commercial plant breeding in the UK
- assess the structural and economic barriers for conducting a plant breeding programme and
- understand how innovation occurs within plant breeding

2.0. Commercial Plant Breeding in the UK

A number of definitions exist for commercial plant breeding and for the purpose of this report UK plant breeding refers to:

> *physical investment into research and development (R&D) activities based in the UK directed towards producing new commercial varieties of plants.*

The focus of this sector has been on improving traits related to increasing yields or quality of the final product. These characteristics are attractive to a producer, as they offer higher returns in an industry with tight margins and, in most markets, restrictive criteria on the quality needed to serve a particular market. One prime example of this is barley, which can serve, at the higher end, the whiskey or beer brewing trade, or be used to produce feed for livestock, which will generate a lower price. The quality of the product is also important to the processing sector, which operates under tight margins and, arguably, greater scrutiny towards environmental standards.

The seed market is served by a small number of UK owned private companies, or by a small number of subsidiaries that are the result of investment in the UK from non-UK sources. In addition, some companies play a role in marketing seed generated from non-UK sources. This latter category requires, in some cases, UK commercial testing and multiplication facilities to ensure the seed is robust and adaptable to UK conditions. This report is focused on the former, that is, companies with premises within the UK who conduct research into plant breeding and who would, as a consequence, provide the UK economy with revenue and employment as a result of plant breeding activity.

The process of plant breeding

Commercial plant breeding follows a number of stages and, dependant on sector, producing a marketable variety can be the product of 20 years development. The process of bringing a seed to market is outlined below:

1) A range of basic, applied and development activities are needed to introduce a new variety into the market. The aim is to generate new genetic diversity using pre-existing genetic material. At the basic end, this includes the identification and introduction of particular traits within a crop or between crops which have economically desirable outcomes. Once crossed these seeds will be sown to produce a uniform first generation (F1) variety

2) The sowing of the F1 varieties introduces genetic diversity for a second generation (F2). This allows ‘lines’ to be grown with attractive traits and successful plantings (over a number of years)

3) The purest lines of crops with the most promising traits will then be ready for multiplication (usually through contracting fields from farmers and trialling for certification)

4) The crops undergo statutory testing before entry into the National List, which determine which varieties are allowed for marketing in the UK. Criteria tests, established since the 1960s, for these new varieties are Distinctness, Uniformity and Stability (DUS). This may take a further two years.

5) Once accepted onto the National List, for the crop to be successful it needs to be placed on a Recommended List. This requires non-statutory trials and highlights particular characteristics which farmers may favour given climatic, economic and market conditions.

6) Finally, the plant breeder needs to invest in variety maintenance to ensure the purity and protection of the material produced. As seed requires to be multiplied for sale, farm land is contracted to grow these lines and produce seed that is sold as certified.

Plant Variety Rights and National Listing

National Listing is a mandatory EU requirement for official registration of new varieties. This applies to the main agricultural and vegetable crop species and it is mandatory for marketing of seed or other propagating material. Once registered on the National List, a variety is then entered on the EU Common Catalogue and becomes freely marketable across the EU.

Intellectual property rights are intended to incentivise long-term investment for producing a new variety. Plant Variety Rights (PVRs) were introduced in the 1960s with the aim of allowing appropriation of returns from plant breeding. PVRs are a voluntary IP right, with the conditions set globally through the 1991 International Convention for the Protection of New Plant Varieties (UPOV Convention). The UPOV Convention only offers protection to new varieties of plants. UPOV does not regulate varieties that are not covered by plant variety protection. Therefore, plant variety protection does not restrict the ability of farmers to grow and sell propagating material of non-protected varieties (UPOV, 2016). Only the breeder of a new plant variety can apply to protect that new plant variety[3].

UPOV provides for a breeder's exemption which allows protected plant varieties to be used to breed new varieties, without infringement of PVRs. Importantly, the authorization of the breeder for the use of protected varieties for breeding purposes is not required under UPOV 1991. Such authorisation shall be required, however, when the repeated use of the variety is necessary for the commercial production of another variety.

UK and EU PVRs both follow the UPOV Convention and are therefore almost identical in their conditions. All species of plants and fungi are eligible. The main difference between UK and EU PVRs is the geographical coverage, with EU PVR enforceable across the entire EU. For this reason, applications for UK PVR are now at a very low level. The much greater geographic coverage available in EU protection is of great benefit to plant breeding businesses.

3 The Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Food and Agriculture separately address the issue of access to genetic resources and benefit sharing.

Within the UK, Plant Breeders' Rights (which equate to PVRs) entitle the holder to prevent anyone doing any of the following acts with respect to the propagating material of the protected variety without authority:

- production or reproduction (multiplication)
- conditioning for the purpose of propagation
- offering for sale
- selling or other marketing
- exporting
- importing
- stocking for any of the purposes mentioned above and
- any other act that may be prescribed by the provisions of the Plant Varieties Act 1997

FERA (2010)

In practical terms, application for National Listing almost always precedes application for PVR. To achieve National Listing the main requirements are to be tested to be distinct, namely to have one or more important characteristics that are different from other varieties; be uniform, i.e. individual plants which have similar or genetically identical important characteristics with very few aberrations, and; be stable, that is to have important characteristics which remain true to their original description after successive propagations or multiplications (DUS). For agricultural species, a variety must also have value for cultivation and use (VCU), which is an evaluation that the new variety will offer improved performance compared to existing varieties.

DUS is also one of the main requirements for PVR. Although the conditions are not completely identical to DUS for National Listing, EU member states and the CPVO have developed an approach to make a DUS report produced anywhere in the EU acceptable for National Listing or PVR by any national or EU authority. The basis for this is CPVO's quality assurance process and resulting network of 'entrusted' DUS Examination Offices. Consequently, the DUS test is done firstly for National Listing, although may subsequently be used for PVR. National Listing is a requirement for marketing, but at the time of application the breeder is uncertain about market potential, especially for agricultural species where the second main requirement is VCU. Only a relatively small proportion of varieties where National Listing is applied for eventually have value in the market, and it is for these varieties that the breeder will want PVR.

Farm Saved Seed (FSS)

Another characteristic of the market is that purchased seed is biological material and is capable of reproduction. Consequently, the farmer may save PVR-protected seed from the first harvest for planting in the next season. Legislation requires that farmers pay royalties on farm saved seed[4]. The British Society of Plant Breeders (BSPB) administers this scheme and farmers pay a royalty payment for the use of these seeds. The first year of certified seed sales is the only year of a variety's life in which a full royalty is paid. The subsequent fees paid for farm-saved seed are required by law to be 'sensibly lower' than the cost of the full royalty. This applies to cereals, fibre plants, fodder plants, oil plants and potatoes.

4 An equivalent legal provision providing a derogation from patent infringement for farm saved seed exists in patent law (Directive 98/44/EC Article 11)

Farm saved seed has created a significant amount of rhetoric both supporting and opposing the process. Ultimately, farm saved seed erodes returns to the producer of the original seed and, it is argued, this dampens the incentive to innovate further within the sector. Saving seed from hybrid seeds is not seen as desirable because the resulting crop will segregate to produce variable offspring, reduced yields and loss of agronomic characters. Hybrid seeds have proven popular since the 1930s and are a common example of how technology can be commercialised to increase appropriability of returns. Ultimately the farmer has a degree of choice in these markets – the higher price of purchasing hybrid seed every year needs to be balanced against the desirable agronomic characteristics of hybrid seed.

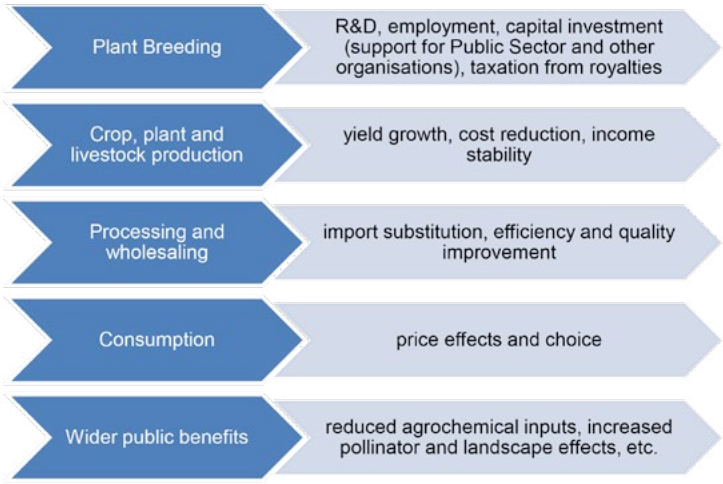
Finally, it should be noted that arrangements for collection of royalties, and approaches to perceptions towards farm saved seeds differ across countries, even within Europe. Ragonnaud (2011) identified only seven EU countries, including the UK, where the payment systems could be deemed to function well. In some countries, namely Spain, Belgium, Bulgaria and Germany systems either did not exist or were considered to be function poorly.

3.0. Mapping the Plant Breeding Sector

3.1. Economic contribution

Commercial plant breeding in the UK will have both a direct contribution to the UK economy, through investment in commercial and public sector research facilities and employment, but will also have a supporting role within the UK food and drinks industry, which consists of production, processing and retailing. This latter effect can be substantial and tends to dwarf the direct contribution. The European Seed Association (ESA) estimated that the value of the European seed market is around seven billion Euros, the value to primary production can be 10 times that (around 70 billion) and higher still with the value of processed goods benefiting from plant breeding (estimated at over 700 billion Euros). (Scholte, 2015)

The different types of economic benefits that emerge from UK plant breeding are shown in Figure 3.1 below:



3.1.1. Direct Economic Contribution

There are currently around 11 businesses who have a serious commercial plant breeding research for the agricultural and vegetable sector, and a further 12 who conduct some form of plant breeding in these sectors. The ornamentals sector is highly fragmented but 13 larger breeders were identified. In addition, there are around another 90 companies involved in the marketing of seed varieties. These tend to be seed merchants or nurseries operating on a small scale basis or acting as agents for UK or foreign produced seed.

UK seed breeding is dominated by transnational corporations (TNC), but includes smaller enterprises and limited companies, such as Mick Pickford Limited and Blackmann Agriculture Limited. These latter companies specialise in a few varietal lines, and tend to reflect the lower end of the scale in terms of direct investment. In addition, there are numerous companies registered who breed for ornamental varieties. These are generally UK based nurseries, though some such as Floranova are transnational operations. The number of breeders within this sector is difficult to quantify as they also include enthusiast breeders of ornamental flowers.

TNCs do not declare national level investments and limited companies are not obliged to disclose this information. Consequently, a questionnaire was submitted to the 36 businesses identified as conducting plant breeding in the UK. This returned 10 questionnaires by the survey deadline, mostly from TNCs, though three emerged from UK based businesses. There were no responses from those in the ornamentals sector.

In total the companies who returned a questionnaire covered 60-70% of market share in a number of agricultural and vegetable markets. In order to derive a figure for total UK investment this was augmented by a previous survey conducted of the UK plant breeding sector in 2015 (ADAS et al., 2015), focused on UK agri-tech businesses. This asked a similar question regarding investment in UK agricultural R&D by type of business. Extracting these individual firm level data, and adjusting for inflation, allowed us to estimate R&D spend for 17 of the plant breeders on our list. The majority were market leaders, and those not represented were relatively smaller scale. Adding a slight weight for these smaller companies allows us to estimate that current UK based R&D expenditure for running plant breeding research equates to £30-40 million per annum. This does not include capital expenditure but did include depreciation within the running costs.

Total turnover of these businesses, again using 17 of the 36 companies as a basis and adjusting for market share gives us an annual turnover in the region of £200-230 Million per year for the sector. Table 3.1 shows the spread of R&D expenditure by SME size category for the 17 firms responding.

Table 3.1. Expenditures on R&D for UK plant breeders, estimated total and average spend per SME category

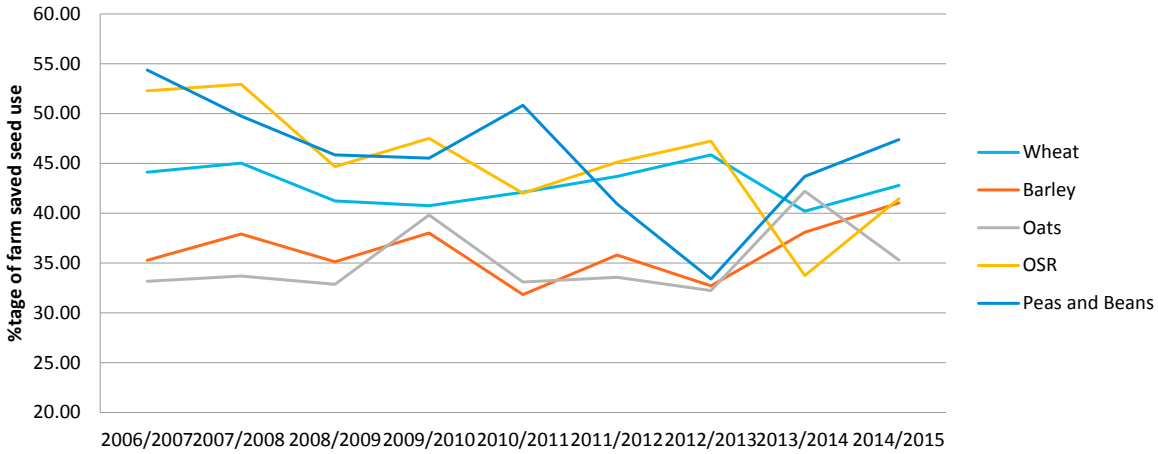
	Total estimated R&D expenditure	Average R&D expenditure	Number of Firms
	617,898	205,966	3
Small	2,891,351	481,892	6
Medium*	26,516,000	3,314,500	8
	30,025,249	1,766,191	17

* Most TNCs are identified as medium sized business at the UK operations level.

Royalties from Certified and Farm Saved Seed

Intrinsic to the cost of seeds are the ability of farmers to maintain saved seeds. If the farmer wishes to save seed of a protected variety from their crop they must declare the amount to the British Society of Plant Breeders (BSPB) who collect a royalty. Figure 3.2 shows the percentage of saved seed to total seed used for several key agricultural crops over time.

Figure 3.2. Farm Saved Seed as a percentage of total seed use for main crops in the UK

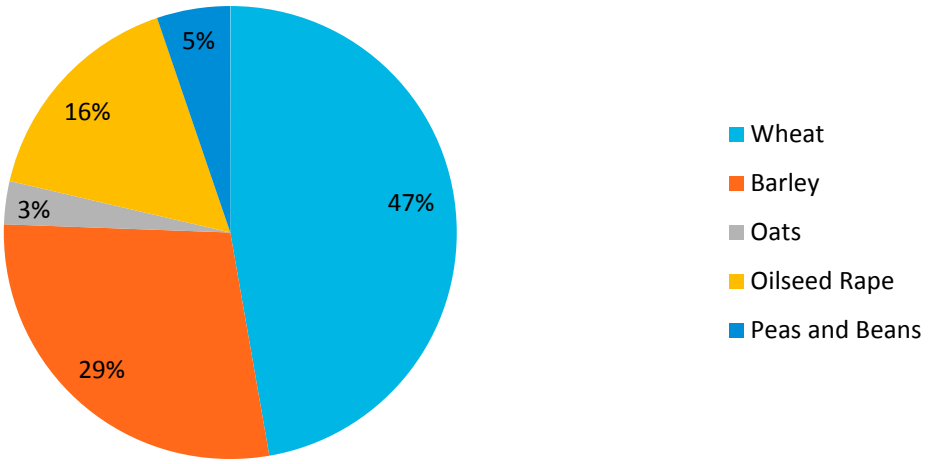


Source: BSPB (2016)

These vary over time and tend to reflect the economic position of farmers, with respect to purchasing seeds, but also a range of factors related to weather and rotation. They differ from around 35 to over 50% for some crops. Ragonnoud (2011) found similar levels for a number of European countries. Poland, Hungary and Finland were found to have higher levels farm saved seed, in the region of 70-80%.

Figure 3.3 shows the spread of royalty payments by crop, taken as an average of the last 9 years, showing returns for wheat, followed by barley, and oilseed rape (OSR), with the remainder generating a smaller share of total royalties.

Figure 3.3 Average Share of Royalties paid on main crop groups (2006/07 – 2013/14)



Source: BSPB (2016)

Value of selling seeds to the UK economy

In addition to the plant breeders in the UK, there are around 90 companies registered for seed production and certification. These range from micro-business to TNCs which provide the input stocks of seeds required for UK plant and crop producers. The value of seeds sales within the UK was estimated at £290 M in 2013 (Fera, 2013).

Imports and Exports of UK seed

Table 3.2 shows the ranking and value in US Dollars of the UK in terms of imports and exports of UK seed for the agricultural, vegetable and ornamental sectors in 2013.

The UK is a net importer of seeds in agricultural, vegetable and ornamental markets. In 2013 prices, the value of exports of UK seeds equated to around £125 million, whereas the value of imports was around £240 million. The UK field crops seed market contributes a large proportion of total export value, at around £101 million, with vegetable seeds around £17 million and ornamentals around £7 million.

Table 3.2 Ranking and Value of trade in seeds for vegetable, field and flower crops, in 2013

Vegetables	Exports			Imports			
Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value	Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value
Netherlands	12,340	1,273	1	Netherlands	17,960	421	1
USA	14,678	550	2	USA	13,540	368	2
France	8,254	404	3	Mexico	1,580	230	3
Chile	1,424	151	4	Spain	5,300	211	4
China	6,119	146	5	Italy	5,725	188	5
Italy	9,548	121	6	France	3,600	151	6
Israel	n.a.	105	7	Japan	5,380	126	7
Japan	1,191	92	8	China	7,800	125	8
Thailand	1,809	74	9	Turkey	2,830	119	9
New Zealand	8,787	67	10	Germany	2,390	84	10
Germany	1,429	66	11	Canada	3,460	81	11
Denmark	10,396	62	12	Korea, Rep. of	2,970	81	12
Spain	887	61	13	**United Kingdom**	**3,700**	**72**	**13**
Korea, Rep.	630	40	14	Brazil	641	70	14
Peru	302	39	15	Russian Fed.	2,020	62	15
Mexico	965	30	16	India	2,555	56	16
United Kingdom	**1,233**	**28**	**17**	Poland	745	54	17

Table 3.2 (continued). Ranking and Value of trade in seeds for vegetable, field and flower crops, in 2013

Field Crops	Exports			Imports			
Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value	Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value
France	593,643	1,467	1	USA	310,446	901	1
USA	314,421	940	2	Germany	253,434	632	2
Germany	162,560	691	3	France	170,852	617	3
Hungary	253,706	402	4	Russian Fed.	57,700	338	4
Netherlands	202,099	346	5	Netherlands	216,332	305	5
Chile	99,886	322	6	**United Kingdom**	**276,178**	**292**	**6**
Canada	203,220	302	7	Italy	575,959	288	7
Romania	109,833	301	8	Belgium	583,618	286	8
Argentina	70,109	282	9	Spain	218,812	226	9
Denmark	133,575	260	10	Romania	51,014	217	10
Belgium	162,869	243	11	Ukraine	43,988	214	11
Italy	98,022	212	12	Poland	197,457	173	12
Spain	117,441	178	13	Hungary	48,131	161	13
Austria	71,998	169	14	Canada	52,500	138	14
United Kingdom	**138,965**	**158**	**15**	Austria	54,362	136	15

Table 3.2 (continued). Ranking and Value of trade in seeds for vegetable, field and flower crops, in 2013

Flowers	Exports			Imports			
Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value	Country	Quantity (Metric Tons)	Value (Millions US Dollars)	Rank by value
USA	690	73	1	USA	449	71	1
Netherlands	955	64	2	Netherlands	1,654	53	2
Germany	342	36	3	Germany	896	21	3
Guatemala	77	23	4	Japan	142	21	4
Japan	30	22	5	**United Kingdom**	**597**	**18**	**5**
France	149	20	6	Canada	793	16	6
Chile	25	18	7	China	20	12	7
China	702	14	8	Italy	1,100	10	8
United Kingdom	**422**	**11**	**9**	France	429	10	9

Source: International Seed Federation (2014)

Whilst there are requirements to monitor imports of seed from third countries, these data are not publically available. However, some commodities, such as forage and oilseeds, as well as flower seeds, are mostly produced outside the UK. France, Germany and Switzerland are the main bases for agricultural and vegetable plant breeding and would be expected to deliver seeds which improve performance for UK growers in mostly cereals and oilseeds markets. The UK is almost totally reliant on cut flowers and ornamentals from non-UK sources, aside from nursery bedding plants, and Holland is the main innovator with respect to this market. In addition, numerous varieties of potatoes are maintained by Dutch breeders. Non-EU countries, through TNCs such as Monsanto, will supply seeds for a number of markets, but are particularly dominant in oilseeds.

Limiting factors to growth

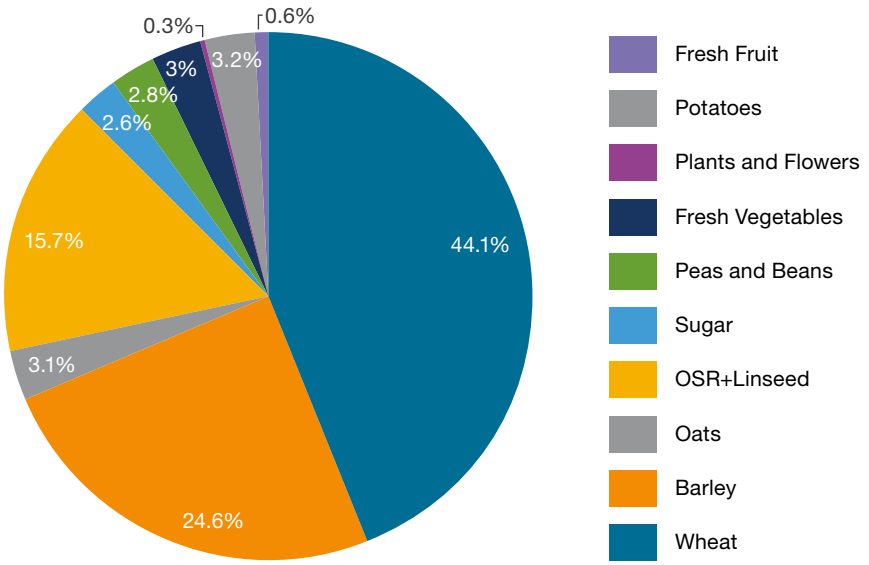
There are two main factors which limit growth within the UK plant breeding sector. Firstly, seed royalties are based on per tonne of seed sold. Consequently, revenue is constrained by the amount of land dedicated to a particular crop, which imposes a ceiling on the size of the market. Naturally, an option is to export seed, but this requires testing and trialling of seed for a range of national conditions, a situation for which the few smaller UK firms do not have the facilities or capacity for. Secondly, the economic health of plant breeding is linked directly to that of the growers and producers. Fluctuations in commodity prices, due to shifts in supply and demand, have led to significant changing economic prospects for the farming and horticultural sectors. Generally, recessions are cyclical but future prices are also dampened by weather, pest and disease effects. Continuing pressures on input cost, along with depressed prices, will generally tend to contract the seed market.

3.1.2. Supporting Contribution

Size and nature of the UK crops, grasses and horticultural markets

Figure 3.4 shows the area of production for major crops grown within the UK. This indicates that cereals - wheat and barley - tend to dominate the cropping profile of the UK, and a cumulative area of 3,016 thousand ha was planted. This is followed by oilseeds (OSR and Linseed) (690 thousand ha). The remaining crops tend to cover only smaller percentages of area but some, such as fruit and flowers, tend to be intensively cropped under covered systems. Total cropped area for 2014 was around 4,400 thousand ha. A small percentage is considered uncropped (through agri-environmental schemes).

Figure 3.4. Area of crops grown in the UK, as a percentage of total cropping area, 2014

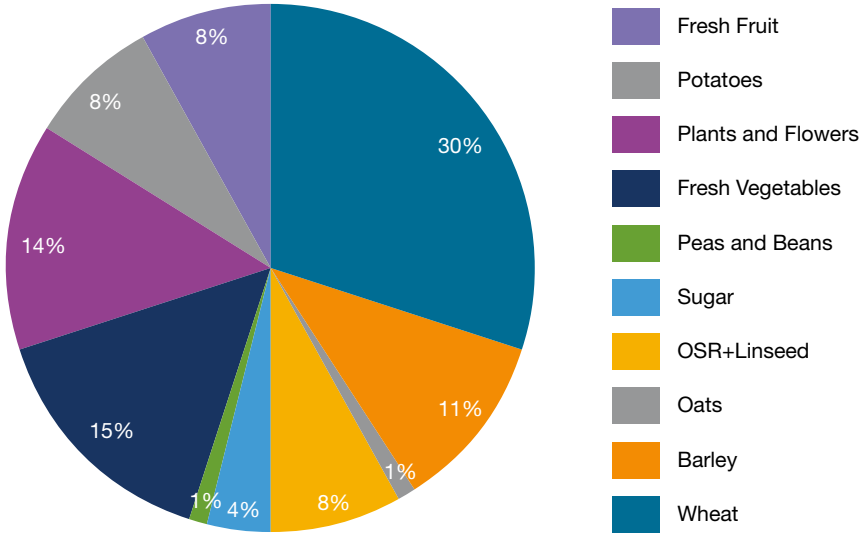


Source; Defra (2015)

Grassland in the UK covers around 11,150 thousand hectares, with 13% of this (1,396 thousand hectares) being temporary grassland, which is more likely to experience seeding and reseeding. The remaining bulk of grassland is permanent, meaning it has been grass for over five years; whilst some reseeding will occur, this will be less intensive than that of temporary grassland.

The total output (at market prices) for the UK crop and plant sector equated to £8,282 million in 2014. The major were wheat (£ 2,471.8M), vegetables (£1,233.6M) and horticultural plants and flowers (£1,166.2M).

Figure 3.5. Total output (at market prices) for the plant growing sector (£ million), 2014



Source: Defra (2015)

Production Level contributions

Yield growth, through genetic improvement, makes a significant economic contribution to farming and the supply chain. From the early 1980s at least 88% of yield increases for the major cereal crops and oilseed rape in the UK are estimated to have arisen through plant genetic improvement (Mackay et al., 2011). Table 3.3 shows the rate of growth over the period 1984-2014, in terms of tonnes per ha for selected crops, along with the average annual growth and standard deviations to indicate how this expected yield fluctuates over time.

Table 3.3. Yield Growth for selected crops, tonnes per hectare, 1984 to 2014

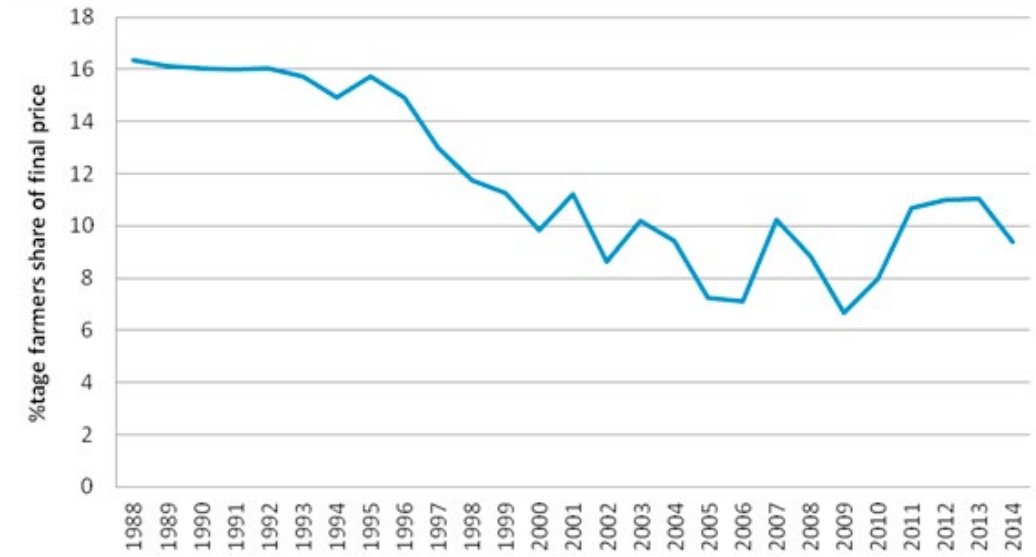
	Cumulative Yield Growth	Standard Deviation	Annual average growth
	t/ha	t/ha	%
Wheat	0.87	0.65	0.7%
Barley	0.81	0.31	0.6%
Oats	1.06	0.34	0.8%
OSR	0.21	0.35	0.8%
Peas and Beans	-0.12	0.70	2.0%
Potatoes	4.81	3.85	0.9%

Source: Defra (2015) Authors Calculation

Average growth in yield has been between 0.6% to 2.0% per annum since 1984. No equivalent estimate exists for the contribution of genetic improvement to vegetable or fodder crops. In addition, breeding goals for ornamentals would include aesthetic as well as resilience-traits which are monetised through the high value paid within ornamental markets.

Farm incomes within the UK have varied significantly throughout the last 30 years, which in part will have been driven by changes in prices of seeds as a key input. Plant breeders have tended to breed for yield improvement and not for stability and the standard deviations above show the variance around the mean yield growth for each crop, which may indicate that these programmes may not have contributed to stabilising farmers' incomes. The additional returns from the market place are dampened by the supply chain. Figure 3.6 shows the farmers share of the final price of a 800g white sliced loaf in percentage terms. Whilst there is fluctuation in the last 10 years the trend seems to be significantly downward and this helps to illustrate that the benefits from crop and plant breeding may be uneven, due to price asymmetries in the supply chain.

Figure 3.6. Farmer share of the final price of a White Sliced Loaf, percent, 1988-2044.



Source: Defra (2015)

Import substitution

Another consequence of higher yields and breeding for adaptation to UK conditions is that the UK's trade balance may be improved by increasing the share of home grown agricultural produce relative to imported goods. Table 3.4 shows the level of self-sufficiency in various crops. This shows the total volume harvested and the percentage of production of new supply emerging from UK growers.

Table 3.4. The amount harvested measured against imports and exports of goods.

	Volume of harvested production (thousand tonnes)	% of total production exported	% of imports to total UK production	Production as % of total new supply for use in the UK
Wheat	16,606.0	7%	11%	96%
Barley	6,911.0	16%	1%	118%
Oats	820.0	8%	4%	104%
OSR+Linseed	2,498.6	15%	4%	113%
Sugar	1,446.0	22%	81%	63%
Fresh Vegetables	2,796.2	4%	78%	58%
Potatoes	5,921.0	8%	30%	82%
Fresh Fruit	426.9	23%	847%	11%

Source; Defra (2015)

There is a wide variance by cropping sector, but the table indicates full self-sufficiency in cereals and oilseeds markets, and high self-sufficiency in potatoes. For vegetables and fresh fruit these are much lower, but tend to reflect the all-year round demand for fresh fruit and vegetables, and the effect of seasonality on growing conditions in the UK.

In addition, the Horticultural Development Council estimated in 2012/13 that £324 million of live bedding plants and £598 million worth of cut flowers were imported to the UK (Denny, 2014). These imports contributed to around 50% of the total value of produce sold in the UK.

Overall returns to plant breeding research

The grown product enters a number of supply chains which increase returns substantially, through value added in processing and handling. Wheat Milling and Flour Making alone add value of around £1 billion to the economy (Defra, AUK, 2015). Other sectors, such as brewing and feed manufacture and production of oils and fats, underpin the UK agri-food and drink supply chain which is worth around £109bn, or 7% of gross value added, to the UK economy (Defra, 2015). Plant breeding contributes significantly to this sector through the supply of crops and vegetables, but also feed and grass seeds for the livestock sector. Denny (2014) estimated that ornamental horticultural production generated around £1 billion to the UK economy for 2012/13 and that it employs around 15,000 people in mostly small scale nursery enterprises.

Whilst it is difficult to estimate an economic value of this contribution, DTZ (2010), in a study funded by the British Society of Plant Breeders, estimated a return on investment of £40 for the production, processing and consumption of UK produced cereal-based products to every £1 spent on breeding. Returns to public research, after their adoption by the commercial sector, are considered high for plant breeding. Thirtle et al. (1998) calculated returns from the introduction of wheat and barley varieties from the UK publically funded Plant Breeding Institute. They found returns of between 14 to 27% for the applied research conducted within the institute. Moran et al. (2007) produced an evaluation of Defra's genetic R&D programme finding rates of return of between 29-61% for productivity benefits, and rates of 43 to 62% from nitrous oxide (N2O) saved. These are illustrated in Table 16 below, and are higher than the recommended rate of return of 3% for public investment (HM Treasury, 2011).

Table 3.5. Rates of return to selected UK research programmes

Breeding Programme Area	Yield and N saved	N2O	All Benefits
Breeding oilseed rape with a low requirement for nitrogen fertiliser	34	48	53
The Defra Oilseed Rape Genetic Improvement Network	29	43	47
Genetic approaches to maintaining wheat yields in a changing environment.	61	56	72
Identification of genetic markers for lodging resistance in wheat.	39	54	59
Investigating Wheat Functionality Through Breeding and End Use.	37	53	58
Controlling soil-borne wheat mosaic virus in the UK by developing resistant wheat cultivars	46	62	68
Median	38	53.5	58.5
Min	29	43	47
Max	61	62	72

Moran et al. (2007)

A further supporting contribution emerges from the public good aspects of plant breeding, which may provide societal benefits as traits such as resilience to climate stress and reduced reliance on chemical inputs are bred within the varieties grown (Noleppa, 2016). Whilst these are traditionally the domain of the public sector, some leverage from commercial activities will engender these benefits to the UK landscape and related ecosystems (Barnes et al, 2015).

4.0. Structural Analysis of the Plant Breeding Sector

4.1 Numbers of supply chains and members

Data, available from the EU Common Catalogue, lists 514 maintainers of UK listed agricultural plant species, and a further 109 maintainers of vegetable plant species. The majority have a base within the UK. However, the bulk of these are agents or public sector organisations maintaining these seeds, rather than organisations developing them from the genetic material. Table 4.1 shows the members of the European Seed Federation with UK facilities, by main plant sector.

Table 4.1. Plant Breeding Companies with Operations in the UK by main cropping group

Cereals	OSR	Potatoes
DSV (UK) Limited	Monsanto	Cygnet Potato Breeders
KWS UK Ltd	Bayer	Caithness Potato Breeders
Limagrain (UK)	Mike Pickford	Mylnefield Research Services Ltd
Elsoms Seeds Ltd (with Saaten Union)	KWS UK Ltd	
Syngenta	DLF Trifolium	
RAGT		
Blackman Agriculture Ltd		
Monsanto		
Bayer		
Just Oats		
LS Plant Breeding		

Grasses	Vegetables	Others
DLF Trifolium	Tozer Seeds	Wherry & Sons
Germinal	CN Seeds	
Barenbrug	Limagrain	
	Elsoms Seeds Ltd	

A number of markets are served and represented by UK plant breeding. The European Seed Association (ESA) membership list gives an indicator of these businesses and their activities (see Table 4.2).

Table 4.2. UK presence and UK players by crop type by European Seed Association Membership

	Members	Direct Members	Direct Members
	UK	UK	UK Presence
Grassland	13	Germinal-IBERS	DLF, Barenburg. DSV-Eurograss, RAGT
Cereals and Pulses	19	Elsoms	Bayer, DSV, KWS SAAT AG, Limagrain, RAGT, Saaten-Union (with Elsoms)
Oil and Fiber	22		Bayer, DSV, KWS SAAT AG, Limagrain, RAGT, Monsanto (DEKALB), Pioneer, Syngenta
Potatoes	14		KWS SAAT AG
Vegetables	12	Elsoms, Tozers	Bayer, Limagrain, Sakato, Syngenta
Total	52		

Source: ESA, 2016

More detailed information on UK plant breeding companies is available from the British Society of Plant Breeders (BSPB), though only 11 companies are full members of the BSPB (Table 4.3). Full membership is open to those who are conducting a serious plant breeding programme in the UK. Associate membership is open to breeders and breeders' agents marketing varieties in the UK. Associated membership of 52 companies includes some breeders.

Table 4.3. BSPB Full Members

Full Members
Alexander Harley Seeds Ltd (Senova Ltd and Cygnet Potato Breeders Ltd.)
DLF Trifolium Ltd
DSV United Kingdom Ltd (Euro Grass Breeding GmbH & Co KG)
Elsoms Seeds Ltd
Germinal Holdings Ltd (BSH)
KWS UK Ltd
Limagrain UK Ltd
LS Plant Breeding
Monsanto UK Ltd
RAGT Seeds Ltd
Saaten Union UK Ltd
Syngenta UK Ltd

Size and Employment of the UK Plant Breeding Sector

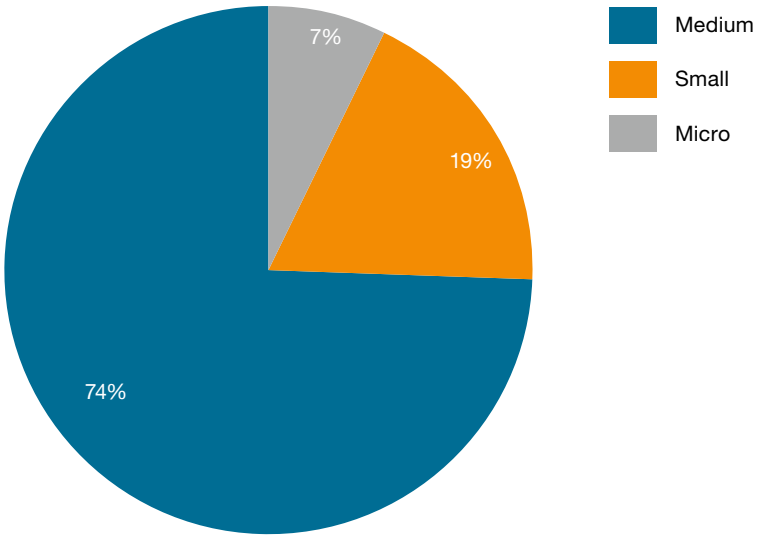
Plant breeding is the province of TNCs and UK based businesses. At the country level the scope of the business ranges from micro to medium sized enterprises. The standard EU definition of SMEs are outlined below

- Micro Business = less than 10 employees & turnover under £2 million
- Small Business = less than 50 employees & turnover under £10 million
- Medium Business = Less than 250 employees & turnover under £50 million

(Source: European Commission (2015)

Levels of employment varies by company, and do not necessarily equate to turnover in terms of the distribution between total staff and those employed within R&D. For instance, one TNC had around 30 UK employees concerned with marketing and support services, but only 1 was directly employed in R&D activities. In total, we estimate around 400 employees are directly employed to conduct R&D in UK commercial plant breeding.

Figure 4.1. Estimated share of employment in plant breeding R&D by size of business



Source: Author's Calculations (based on survey data)

4.2. Level of market share

The bulk of companies involved in plant breeding tend to declare turnovers either globally or at the European Union (EU) level. The ESA identifies 7,200 companies who currently operate within the EU. The value of the seed market was estimated to be seven billion Euros in 2014, employing around 52,000 people in a range of capacities, with 12,500 employed to conduct R&D (ESA, 2014). A further estimate provided by the ESA is that about 15% of turnover will be spent on R&D, which equates to one billion Euros per annum.

There are 520 maintainers of UK marketed seed[5]. Ragonnaud (2013) estimated that, on tonnage of agricultural and vegetable seeds sold, the UK's relative share of the EU seed market is 5%, with France commanding around 31% of the total market (Limagrain, RAGT) and Germany 13% (Bayer, KWS, DVS). Collectively with Spain and Italy these countries control around 60% of the EU market. Notably this does not include ornamentals, where countries such as the Netherlands would dominate.

Table 4.4. Domestic Seed Markets in the EU (Million Euros)

Member States	2005	2006	2007	2008	2009	2010	2011	2012	Share of EU Market (2012)
Fance	1,101	1,537	1,532	2,040	2,294	2,338	2,586	**2,179**	31%
Germany	804	796	673	628	811	951	841	**911**	13%
italy	522	621	730	510	513	588	514	**597**	8%
Spain	241	239	328	306	323	339	323	**514**	7%
Netherlands	241	166	219	204	384	441	420	**456**	6%
United Kingdom	458	205	292	272	287	302	323	**350**	5%
Czech Republic	121	159	219	204	215	226	219	**237**	3%
Hungary	161	159	219	204	215	226	216	**233**	3%
Poland	322	207	255	238	186	196	187	**218**	3%
Sweden	161	123	175	163	172	181	180	**195**	3%
Romania			161	150	158	166	158	**171**	2%
Denmark	161	135	182	136	118	140	165	**170**	2%
Greece	113	112	175	163	172	181	172	**156**	2%
Belgium	104	104	139	129	133	140	133	**144**	2%
Finland	64	82	117	109	115	121	115	**125**	2%
Austria	137	135	109	102	108	113	108	**113**	2%
Bulgaria			88	82	86	91	86	**93**	1%
Slovakia	72	72	80	75	79	83	79	**86**	1%
Ireland	48	48	58	54	57	60	57	**62**	1%
Portugal	48	48	58	54	57	60	57	**62**	1%
Slovenia	24	24	29	27	29	30	29	**31**	0%
Total EU	**4,903**	**4,972**	**5,839**	**5,849**	**6,511**	**6,974**	**6,968**	**7,106**	**100%**

Source: PolDep B elaboration based on data recieved from the International Seed Federation. The data includes field crops, vegetable and flower seeds for planting, which are sold to end users. Seed potatoes are not included. Market values were converted from US dollars to euros using annual eschange rates retrieved from the Eurostat database.

Source: Ragonnaud (2013)

5 A maintainer of seed may infer past or present activity in plant breeding, though it historically identifies holders of a particular genetic material

UK estimates of market shares

Annual weight of tonnage seed sold is collected each year by the Scottish, Northern Irish and English and Welsh plant health agencies. These identify the varieties and amount of tonnage sold through UK markets and can be used to identify breeder and parent company in order to calculate market share, as in the charts presented below. Ideally, estimates would be based on value of product, rather than on tonnage sold, but these data are not collected. Hence, whilst plant health agencies provide a source of data for estimating market share, there are caveats as seed may be stored rather than planted that same year. Similarly, in markets where the majority of seeds are from imports, namely oilseeds, there is a significant bias in the estimates presented here. Finally, no similarly available data exist for vegetable or ornamental varieties; consequently, we cannot replicate this analysis for these sectors.

Figure 4.2. Estimated UK market share for wheat

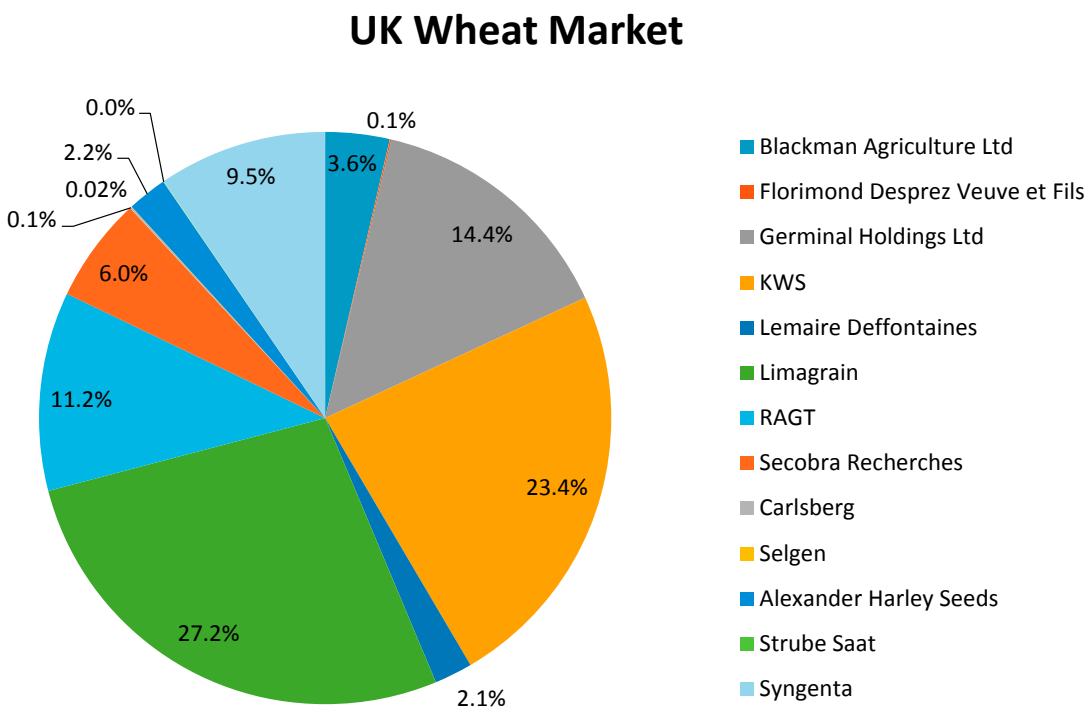


Figure 4.3. Estimated UK market share for barley

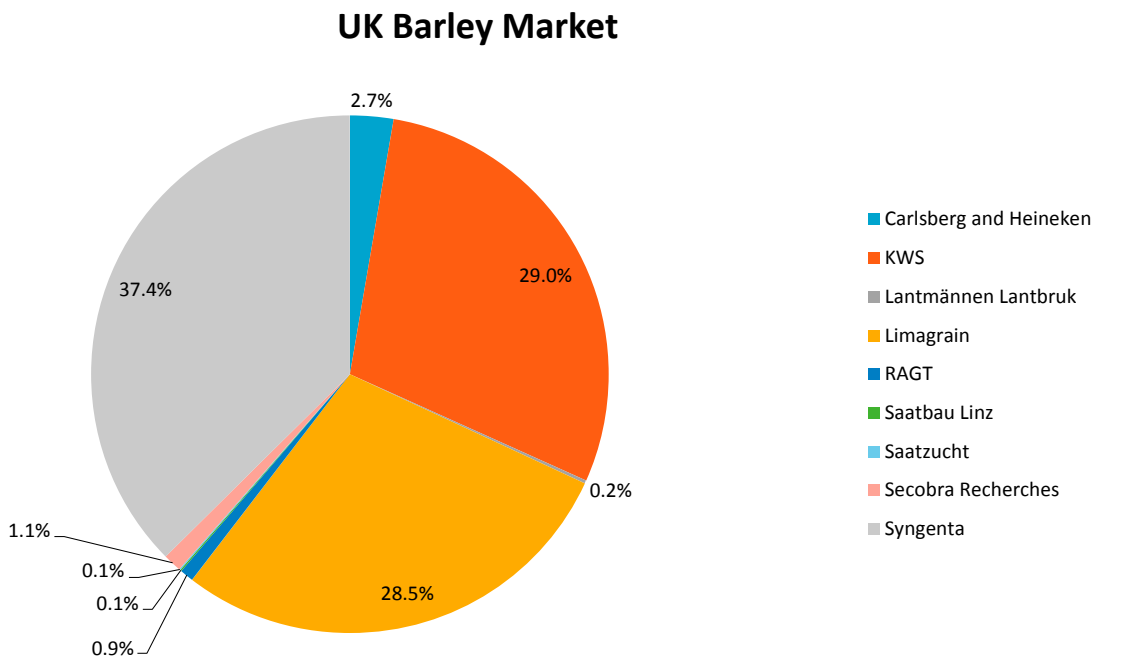
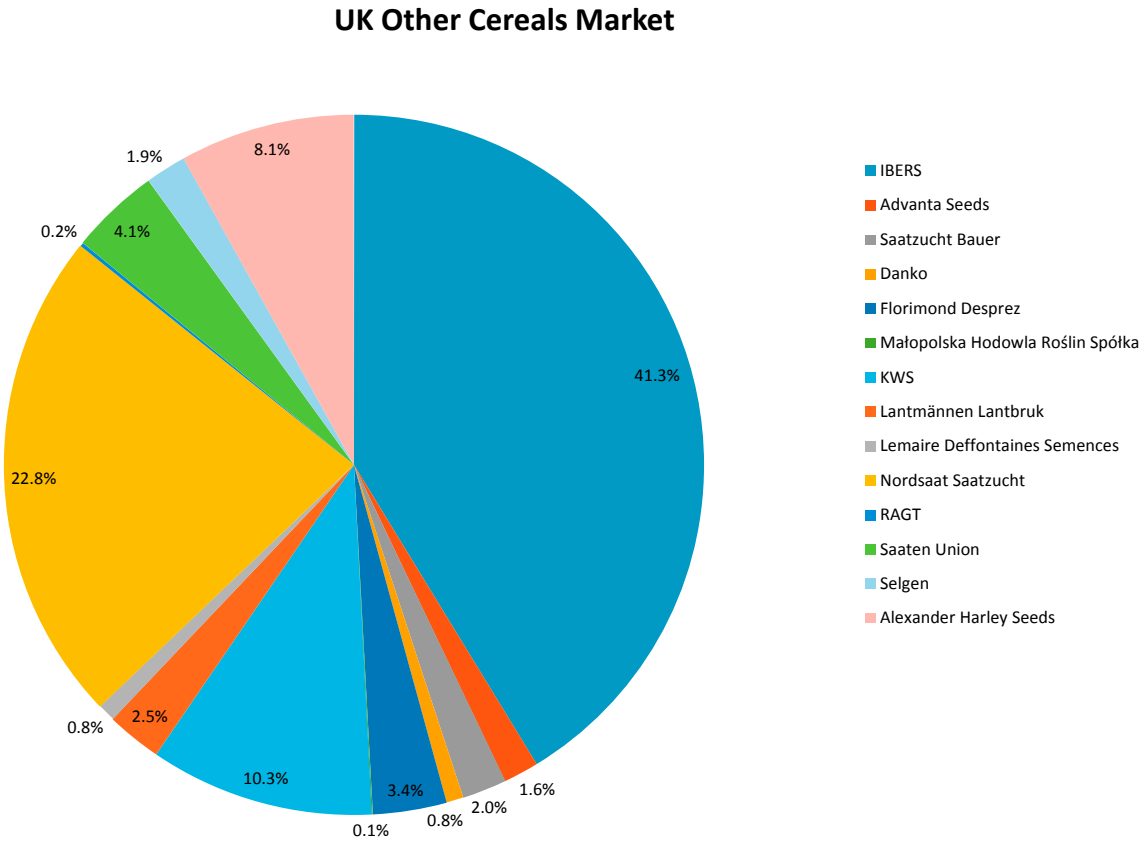
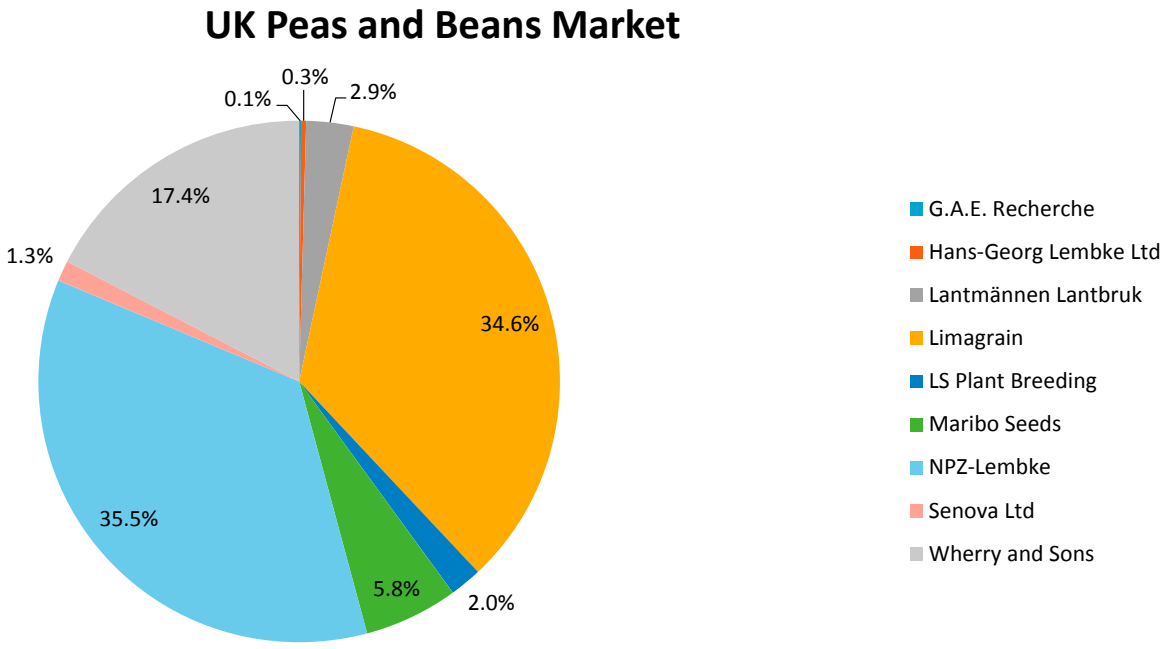


Figure 4.4. Estimated UK market share for other cereals



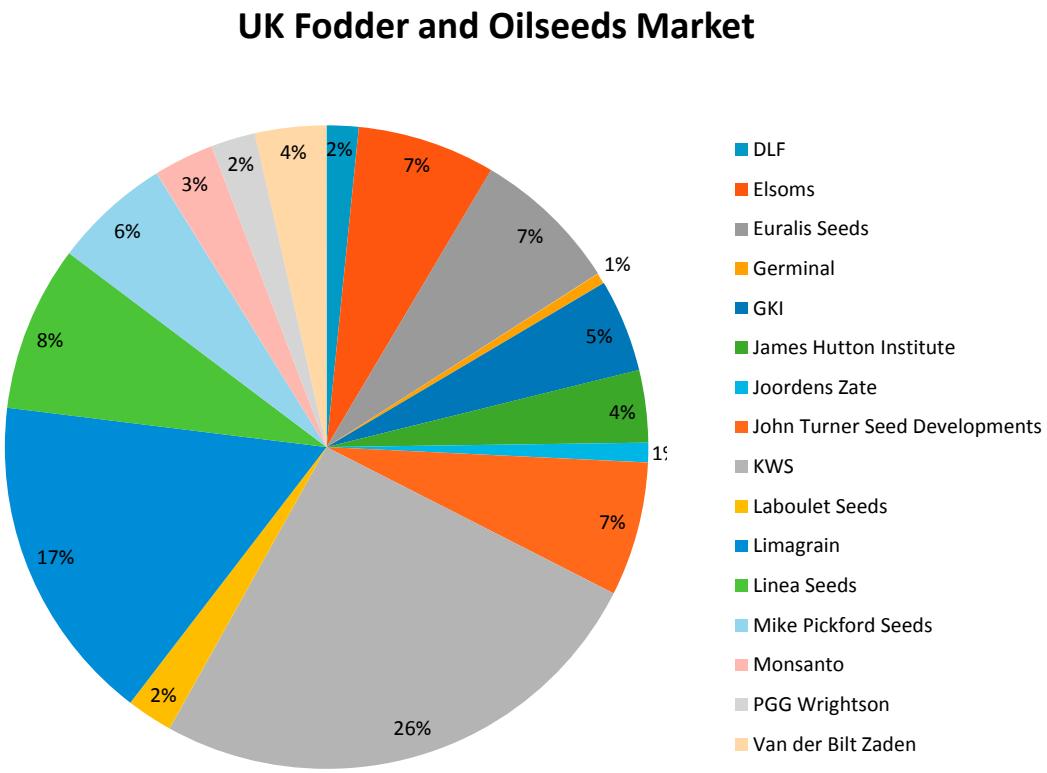
Cereal markets are dominated by a small number of players. In the UK wheat market, both Limagrain and KWS dominate with around 25-30% of the market. This is followed by Germinal Holdings, RAGT and Syngenta who hold around 10-15% each of the market. The barley market has three major players, Limagrain, Syngenta and KWS who each hold around 30-35% of the market. Carlsberg and Heineken have a small share of the market through their null-lox variety which offers improved traits for beer brewing. The other cereals market, tends to have European mainland breeders as some of the crops are quite specialised, such as spelt and triticale. There are two major players, namely Danko Hodowla Roślin Sp. z o.o. (Danko) which is a Polish based breeding company who produce triticale for the UK market, and IBERS, through Aberystwyth University, who are the market leaders in spring and winter oats for the UK market.

Figure 4.5. Estimated UK market share for peas and beans



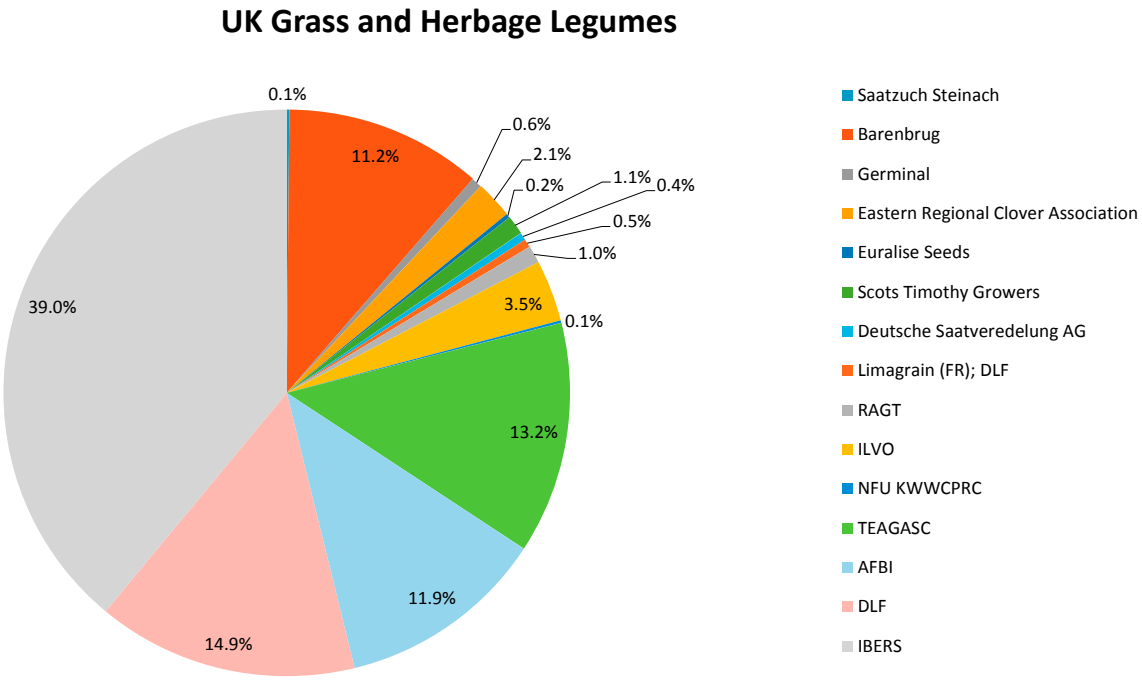
Peas and beans are either grown for human or animal feed. This market is dominated by Limagrain and Norddeutcsche Pflanzenzucht Hens-Lembke KG (NPZ-Lemke), a German plant breeder. Both companies specialise in peas and beans. Wherry and Sons, are British legume breeders who own around 17% of the market.

Figure 4.6. Estimated UK market share for fodder and oil seeds



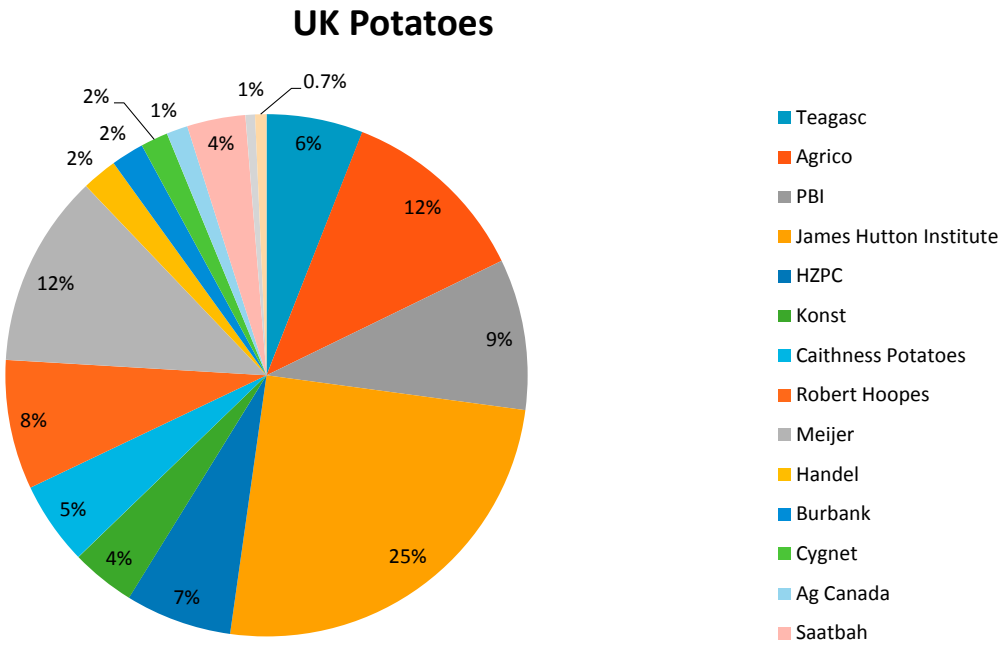
The UK Fodder and Oilseeds markets are fragmented and are biased by imports which are not recorded in these figures. This market includes fodder crops such as swede and kale, and oilseeds, such as linseed and oilseed rape. The Advance variety, bred by the UK breeder Mike Pickford seeds, has around 11% of the Winter Oilseeds market. However, KWS has around 26% share of the market, followed by Limagrain with a 17% market share.

Figure 4.7. Estimated UK market share for grass and herbage legumes



Grass and herbage legumes comprise rye grasses, clover and protein legumes such as blue lupins. Again, these figures only reflect the domestic market and there will be imported seed into this market which is not shown. Notably, this market is dominated by publically funded research institutes, namely IBERS, AFBI, ILVO and Teagasc, but also commercial breeders such as DLF, RAGT and Limagrain.

Figure 4.8. Estimated UK market share for potatoes



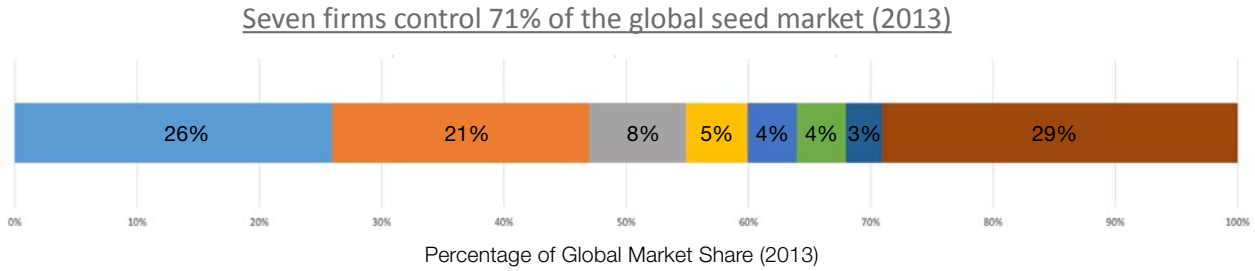
The UK potato market is dominated by PVR-free varieties and, as such, some of the members of this market are maintainers of the variety rather than direct breeders. The publically funded breeders PBI, Teagasc and the James Hutton Institute maintain PVR-free varieties. A number of companies with higher market share, such as Handel and Meijer, are based in the Netherlands, but Caithness Potatoes who have 5% of market share are based in Scotland.

4.3. Level of market concentration and power

Global market position

The global agribusiness sector has increasingly consolidated through horizontal acquisition of related seed companies as well as vertical integration with agro-chemical activities; for instance, Syngenta and BASF are agricultural chemical companies who have divested into seed breeding through acquisition and cross-licensing. Howard (2009) examined increasing power in the seed industry. He showed graphically how concentration has occurred over the last 30 years within global seed markets by capturing the markets for most major crops through a series of acquisitions and mergers. Consolidation of the seed industry increased rapidly from the mid-1990s, when patented transgenic crops were commercialized (Howard, 2015). In addition this consolidation was also driven by acquisitions from agrochemical companies. These are now commonly known as the big six companies (Monsanto, DuPont, Syngenta, Bayer, Dow and BASF) (Moretti, 2006). According to ETC Group (2015) three firms own around 55% of the global seeds market (Monsanto, 26%; DuPont, 21%, Syngenta, 8%).

Figure 4.9 Global Seed market share, 2013



Source: ETC Group (2015)

- Monsato (26%)
- DuPont (21%)
- Syngenta (8%)
- Limagrain (5%)
- Dow AgroSciences (4%)
- KWS (4%)
- Bayer CropScience (3%)
- Others (29%)

In the U.S Howard (2015) points out that domination of seed patents is higher, with the top three companies owning 85% of corn patents and 70% of non-corn patents (Glenna and Cahoy, 2009). Figure 4.10 indicates a more dispersed pattern for the global vegetable market in 2013. Even so, concentration emerges with four firms owning 44% of the vegetable seed market.

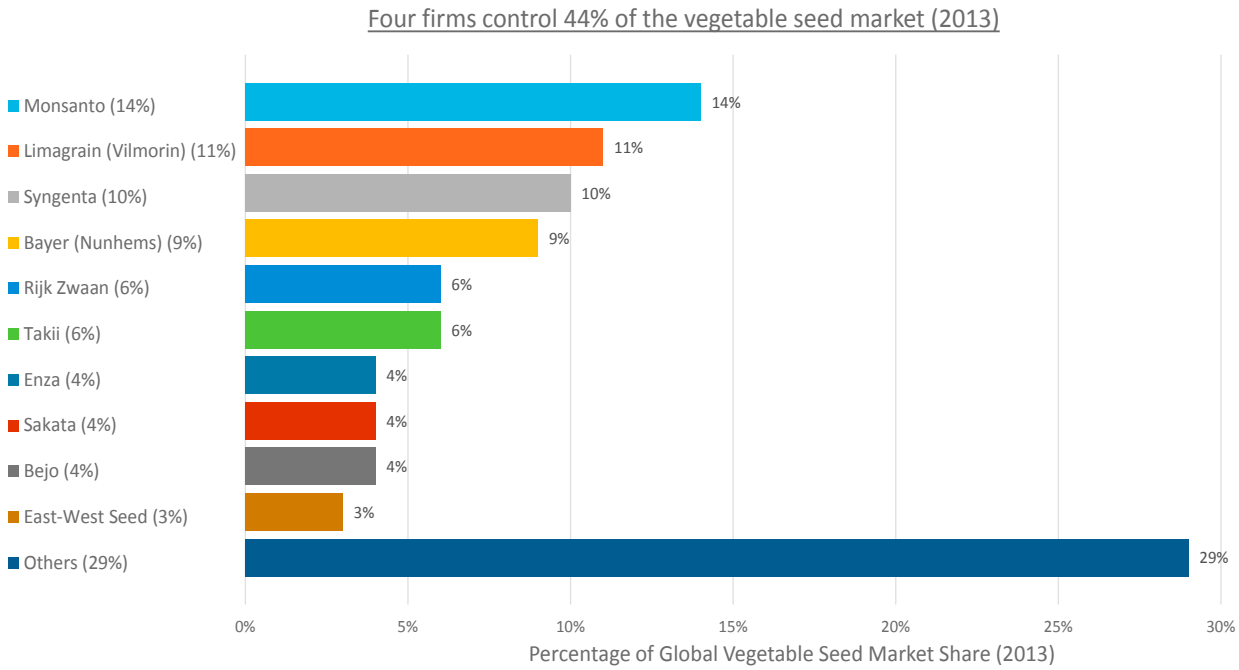


Figure 4.10. Global share of vegetable seed markets, 2013.

Source (ETC Group, 2015)

Generally, this consolidation has led to higher seed prices in the US, which doubled over the 1990-2010 period relative to the prices farmers received for their crops (ETC Group, 2015). In the EU, the price of seeds rose by 30% from 2000 to 2008, though it may also reflect changing market conditions. The vertical integration between agro-chemicals and seeds has led to single packages being offered by these companies, with both seed and complementary chemical treatments being sold to farmers; though these are less common in the UK and in some other EU markets.

EU Market Concentration

Table 4.5 shows the main seed companies who operate in the EU market, their turnover in Europe and estimated market share and number of employees. This exercise is complicated by most of the companies being TNCs and, therefore, possibly not declaring returns at a European level. As such, the table below can only provide estimates.

Table 4.5. Main Seed companies on the EU market, estimated turnover, market share and number of employees

Company	Estimated Turnover*	Estimated share of the total EU market	Number of Employees
	(Euro Million)	%	Number
Syngenta (Switzerland)	857	12	12,417 in Europe, Africa and Middle East
Limagrain (France)	722.5	10	5,304 in Europe
KWS (Germany)	657	9	2,815 in Europe
Bayer CropScience (Germany)	310	4	20,800 (worldwide)
DLF-Trifolium (Denmark)	259	3.5	649 in 12 countries

* Either in EU, in Europe or Europe +

Source: Ragonnaud (2013)

Out of the big six major global players (shown in Figure 4.10) four are European and control around 35% of the European seed market.

Concentration in the UK Sector

Estimating concentration at the UK level is complicated by cross-border issues of attribution of profits from breeding programmes developed in the UK. A range of indicators have to be explored to understand concentration at the UK level.

A prominent source is the Plant Varieties and Seeds Gazette published annually by the Animal and Plant Health Agency (APHA, 2016). This gives the list of varieties currently maintained for marketing within the UK. More usefully it assigns the varieties held by maintainer. The section below shows summary statistics for each plant sector by frequency of varieties held. This offers a proxy indicator for research concentration, as the companies maintaining more varieties tend to be mostly representative of the TNCs identified above.

Agricultural Crops

Table 4.6 shows the frequency of varietal ownership within the cereals sector. Nearly half of all varieties are owned by 6 maintainers, with an average of 51 cereal varieties being held by these companies.

Table 4.6. Cereal varieties by number of maintainers, share of total varieties held per maintainer and average no of varieties held.

Number of Varieties Held	1	2-5	6-9	10-24	25+
Number of Maintainers	36	23	10	12	6
Share of Total Varieties Held	6%	10%	11%	27%	47%
Average No of Varieties Held	1	3	7	15	51

Table 4.7 identifies these six top maintainers for cereals. Only Aberystwyth University (through IBERS) have their headquarters in the UK, and they hold 5% of all varieties. The varietal lists are dominated by EU TNCs, with Limagrain holding 12% of all varieties and KWS holding 13% of all varieties.

Table 4.7. Cereal varieties top maintainers, share of total varieties held per maintainer and country of head office.

Name	Number of Varieties Held	% of Total Varieties	Country of Head Office
Aberystwyth University	30	5	UK
KWS Saat AG	33	5	Germany
RAGT 2N	35	5	France
Syngenta UK Ltd	47	7	Switzerland
Limagrain UK Ltd	75	12	France
KWS UK Ltd	86	13	Germany

Within Beet production the level of concentration of varieties is higher, which is reflective of the lower absolute number of maintainers in the sector. Hence three maintainers hold 73% of all beet varieties which are marketable within the UK.

Table 4.8. Beet varieties by number of maintainers, share of total varieties held per maintainer and average no of varieties held. Top maintainers listed and characterised below.

Number of Varieties Held	1	2-5	6-9	10-24
Number of Maintainers	0	2	3	3
Share of Total No of Varieties	0%	6%	21%	73%
Average No of Varieties Held	0	2	8	17
Top maintainers for beet varieties				
Name	**Number of Varieties Held**	**% of Total Varieties**	**Country of Head Office**	
Syngenta Winter Oilseed AB	9	13	Switzerland	
Strube GmbH & Co KG	13	19	Germany	
Sesvanderhave NV/SA	18	26	Netherlands	
KWS Saat AG	20	29	Germany	

For Fodder crops, which includes grassland and agricultural feed crops, there are eight companies who maintain 55% of the varieties held for the UK market, though the numbers of varieties vary from 25 up to 79 (for DLF). Here, two UK companies attached to public research institutes are represented, namely Aberystwyth, through IBERS, and, AFBI.

Table 4.9. Fodder varieties by number of maintainers, share of total varieties held per maintainer and average no of varieties held. Top maintainers listed and characterised below.

Number of Varieties Held	1	2-5	6-9	10-25	25+
Number of Maintainers	41	31	12	2	8
Share of Total No of Varieties	7%	16%	16%	5%	55%
Average No of Varieties Held	1	3	8	15	38
Top maintainers for fodder varieties					
Name	**Number of Varieties Held**	**% of Total Varieties**	**Country of Head Office**		
Syngenta Seeds GmbH	25	5	Switzerland		
Norddeutsche Pflanzenzucht	25	5	Germany		
Limagrain UK Ltd	26	5	France		
Agri-Food and Biosciences Institute (AFBI)	27	5	UK		
Aberystwyth University	38	7	UK		
Saatzucht F R Strube	39	7	Germany		
Pioneer Genetique SARL	42	8	France		
DLF Seeds A/S	79	14	Denmark		

Within Oil and Fiber plants there is a greater dispersion of maintainers, with only one company holding more than 25 varieties in the UK market (Monsanto). JTSD (John Turner Seed Developments), a relatively new small UK company involved in seed processing for propagation, owns around 7% of total varieties in this sector.

Table 4.10. Oil and Fiber varieties by number of maintainers, share of total varieties held per maintainer and average number of varieties held. Top maintainers listed and characterised below.

Number of Varieties Held	1	2-5	6-9	10-25	25+
Number of Maintainers	28	21	6	5	1
Share of Total No of Varieties	11%	27%	17%	30%	15%
Average No of Varieties Held	1	3	7	14	36
Top maintainers for oil and fibre varieties					
Name	**Number of Varieties Held**	**% of Total Varieties**	**Country of Head Office**		
SA A Momont Hennette et ses Fils	13	5	France		
Limagrain UK Ltd	15	6	France		
Euralis Semences	16	7	France		
JTSD Ltd	18	7	UK		
Monsanto UK Ltd	36	15	US		

The potato sector has one company owning more than 25 varieties. This reflects the longer development time needed to breed potato varieties. These varieties are not only dominated by UK companies, but also, with the Science and Advice for Scottish Agriculture (SASA), represent the PVR free nature of potato varieties still maintained and planted in the UK.

Table 4.11. Potato varieties by number of maintainers, share of total varieties held per maintainer and average no of varieties held. Top maintainers listed and characterised below.

Number of Varieties Held	1	2-5	6-9	10-25	25+
Number of Maintainers	17	11	6	2	1
Share of Total No of Varieties	10%	21%	25%	23%	21%
Average No of Varieties Held	1	3	7	21	37
Top maintainers for potato varieties					
Name	**Number of Varieties Held**	**% of Total Varieties**	**Country of Head Office**		
Greenvale AP PLC	8	5	UK		
James Hutton Institute	9	5	UK		
Cygnet Potato Breeders Limited	20	11	UK		
Caithness Potatoes Ltd	21	12	UK		
Science & Advice for Scottish Agriculture	37	21	UK		

Vegetables represent a diverse group of varieties and sub-commodity groups, but for brevity these are represented as one planting group in the table below. Thus, five companies maintain 56% of the varieties within the vegetable sector.

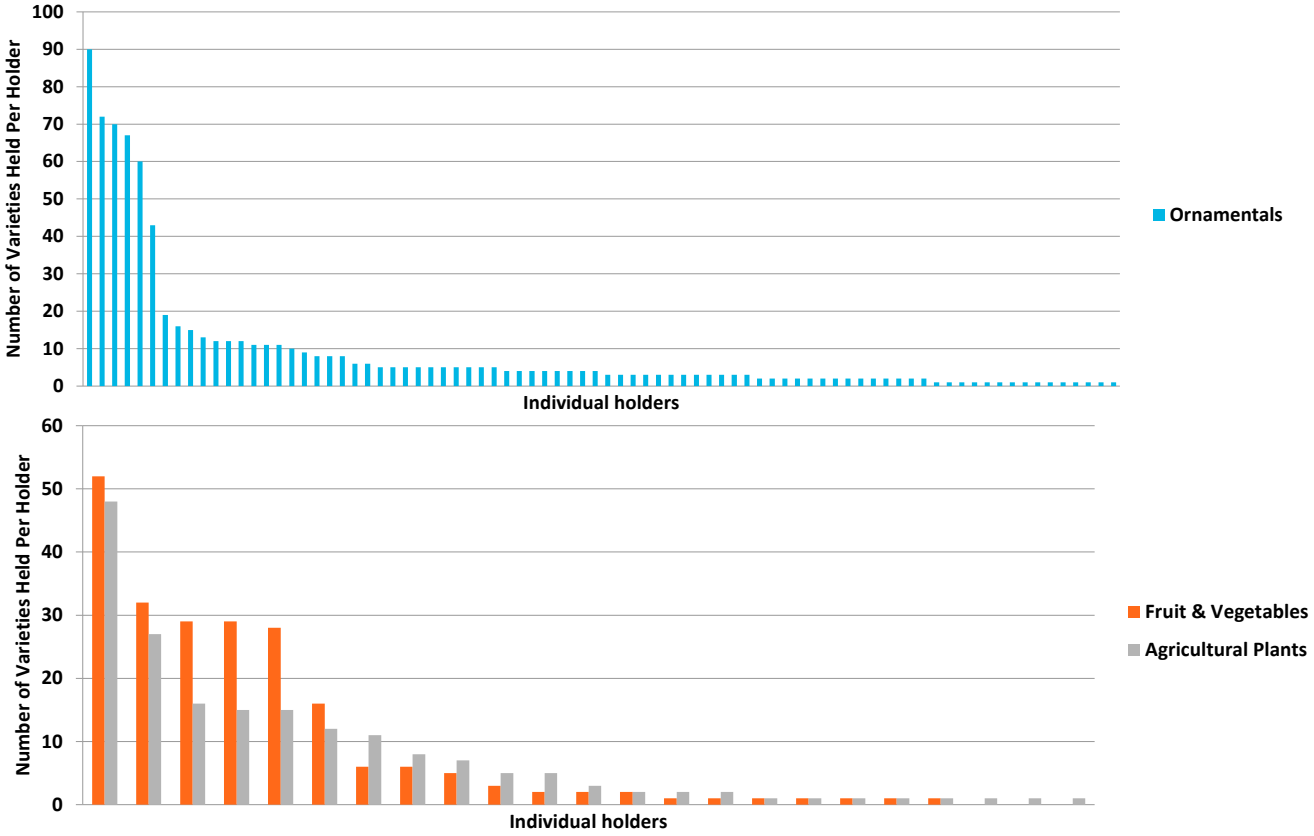
Table 4.12. Vegetables varieties by number of maintainers, share of total varieties held per maintainer and average no of varieties held.

Number of Varieties Held	1	2-5	6-9	10-24	25+
Number of Maintainers	34	15	9	8	5
Share of Total No of Varieties	5%	8%	10%	21%	56%
Average No of Varieties Held	1	4	8	17	73
Top maintainers for vegetable varieties					
Name	**Number of Varieties Held**	**% of Total Varieties**	**Country of Head Office**		
Burpee Europe Limited	24	4	UK		
Shamrock Seed Company Inc	32	5	US/France		
Pro-Veg Seeds	35	5	UK		
E W King & Co Ltd	69	10	UK		
Science & Advice for Scottish Agriculture	112	17	UK		
A L Tozer Ltd	119	18	UK		

Grant Holders of EU Plant Variety Rights (PVR)

Another indication of UK concentration are the number of holders of EU plant varietal rights. The plant breeder can apply for protection in the UK or the EU market. Generally, application is done at the EU level, as it offers protection in European markets. The Community Plant Variety Database is a register of owners of PVRs. Extracting the UK holders by species and by grant year gives an indication of the number of PVRs in place and the frequency of PVRs held by single breeders. This currently identifies 205 holders of grants and 1,249 PVRs in force for the UK. Figure 4.11 shows the distribution of ownership across the three main plant groups of agricultural, fruit and vegetables, and ornamentals. The ornamentals sector has the majority of PVRs in force, (835 or 66% of the total PVRs), with 17 companies or individuals holding 10 or more PVRs. Fruit and vegetable varieties have 219 PVRs (18%), with 6 companies holding more than 10 PVRs. The remaining PVRs (15%) are related to agricultural crops and 7 companies own more than 10 PVRs.

Figure 4.11. Dispersion of ownership of UK PVRS by plant sector, 2016 extraction:



Source: CPVO Database (2016)

Indices of Concentration

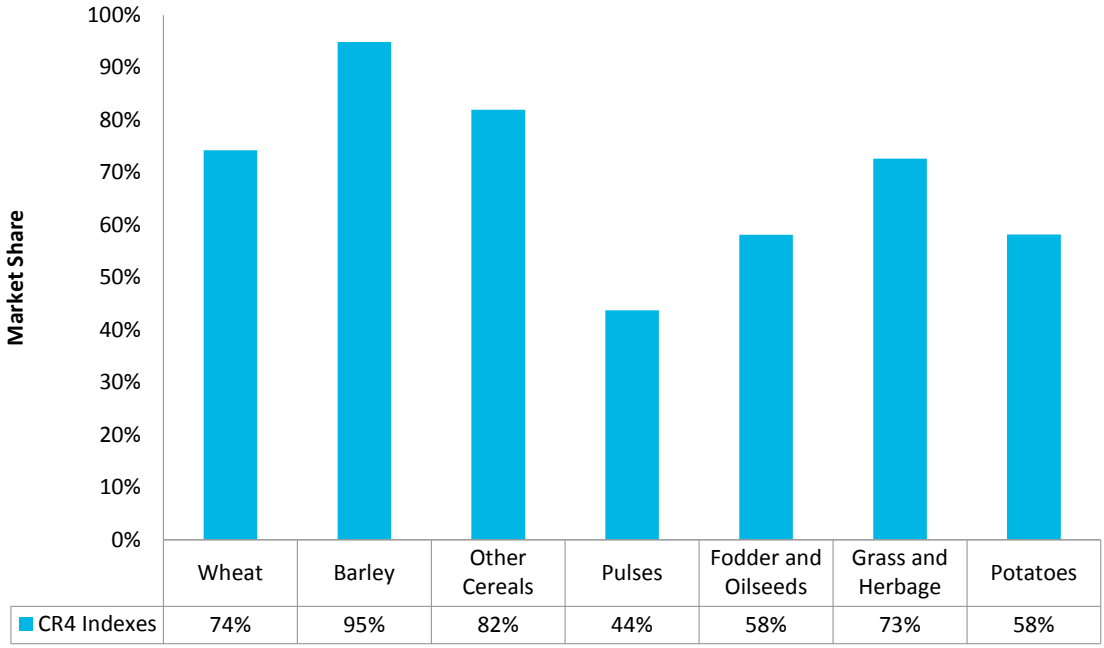
Two indexes were used to identify concentration. A standard indicator is the CR4 index, which sums the market share of the top 4 firms within any sector relative to total market share. Hence the closer to 100% indicates increased concentration.

Different bands of concentration infer:

- **Low concentration:** 0% to 50%. This category ranges from perfect competition to an oligopoly.
- **Medium concentration:** 50% to 80%. An industry in this range is likely an oligopoly.
- **High concentration:** 80% to 100%. This category ranges from an oligopoly to monopoly.
- **Total concentration:** 100% means an extremely concentrated oligopoly. If for example CR1= 100%, there is a monopoly.

The figure below shows CR4 indexes for various agricultural plant markets. The cereals sector seems to have the highest levels of concentration, with barley and other cereals proving the most concentrated with CR4 indexes of over 80%. This infers a highly concentrated market.

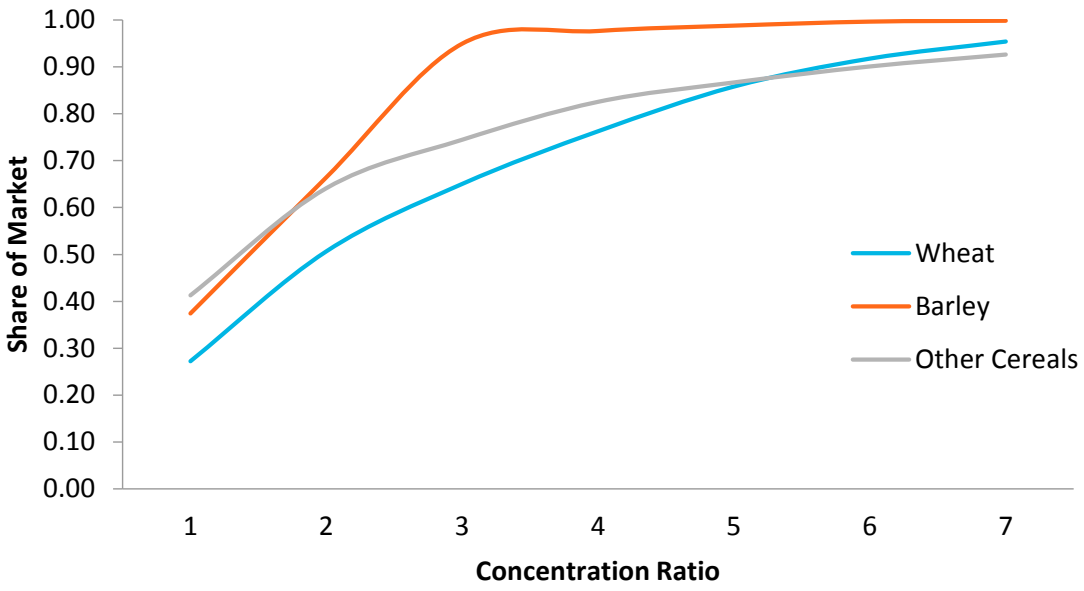
Figure 4.12. CR4 Index of Concentration for agricultural plants



	Wheat	Barley	Other Cereals	Pulses	Fodder and Oilseeds	Grass and Herbage	Potatoes
CR4 Indexes	74%	95%	82%	44%	58%	73%	58%

Similar levels of concentration have been found for agricultural input markets, such as pesticides and oils and fat markets (ONS, 2006). Figure 4.13 shows the cumulative market share across the three cereal sectors to illustrate how the rate of concentration increases as more firms are added to the concentration ratio. This is quite explicit in the barley sector, where the top three breeders control 95% of market share.

Figure 4.13. Concentration Ratios for Cereals markets



The Herfindahl-Hirschman index (HHI) can also be calculated to estimate market concentration. This simply presents the sum of the squares of the market share within a sector. The act of squaring puts more weight, within the index, on those companies with a larger market share. Hence, it covers all breeders within each sector, unlike the CR4 index, to show market concentration levels.

Table 4.13. Herfindahl-Hirschman Indexes for UK plant breeding sectors

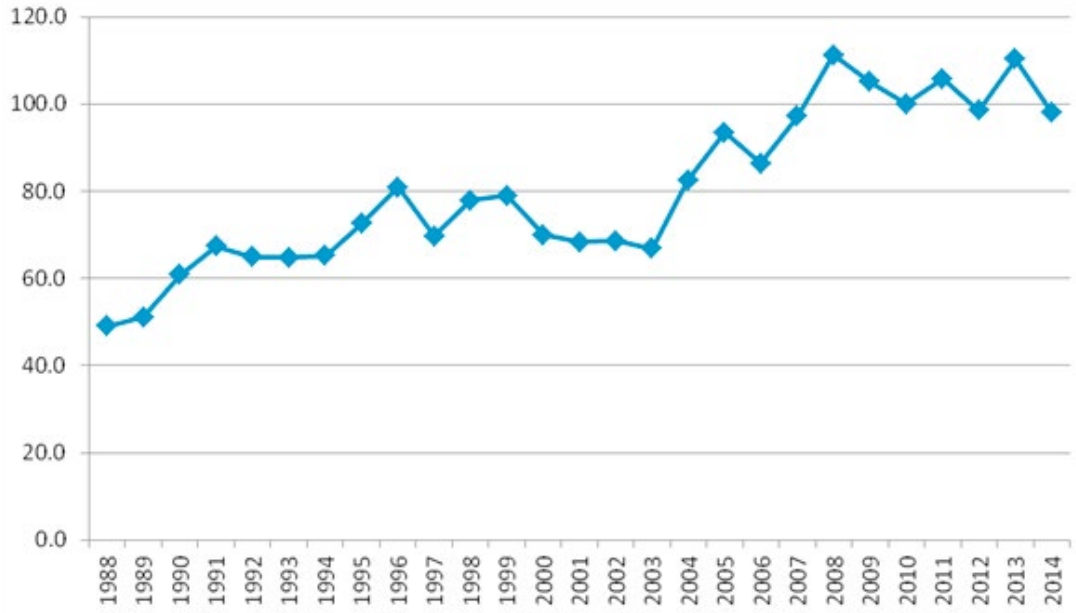
	H-HI
Wheat	1,773
Barley	3,064
Other Cereals	2,441
Pulses	617
Fodder and Oilseeds	1,252
Grass and Herbage	2,204
Potatoes	1,212

As a rule, markets with a score of less than 1,000 are considered to be a competitive marketplace and this only applies to the pulses market. Those with a result of 1,000 to 1,800 are moderately concentrated, which covers wheat, fodder and oilseeds and potatoes. Anything above 1,800 is considered to be highly concentrated. Hence, barley, other cereals and grass and herbage markets match this. This latter market is dominated by imports, and in reality will be less concentrated, but barley and other cereals are the most concentrated sectors in UK plant breeding.

The price of seeds for UK farmers

A common indicator used to reflect the impact of increased concentration is changes in the prices of seeds. Figure 4.14 shows the price index for seed in real terms. This has doubled over the period 1988 to 2014, with substantial increases occurring in the 2003 to 2008 period. This may coincide with increasing acquisition within the plant breeding sector, but also represents global factors, mainly the rise in the value of the Pound to the Euro and the Dollar. Only in the latter years of the study is there a flattening in seed prices, reflecting perhaps the ongoing recession in the farming industry[6].

Figure 4.14. Price Index for Seeds, 1988-2014 for UK agriculture (2010=100)



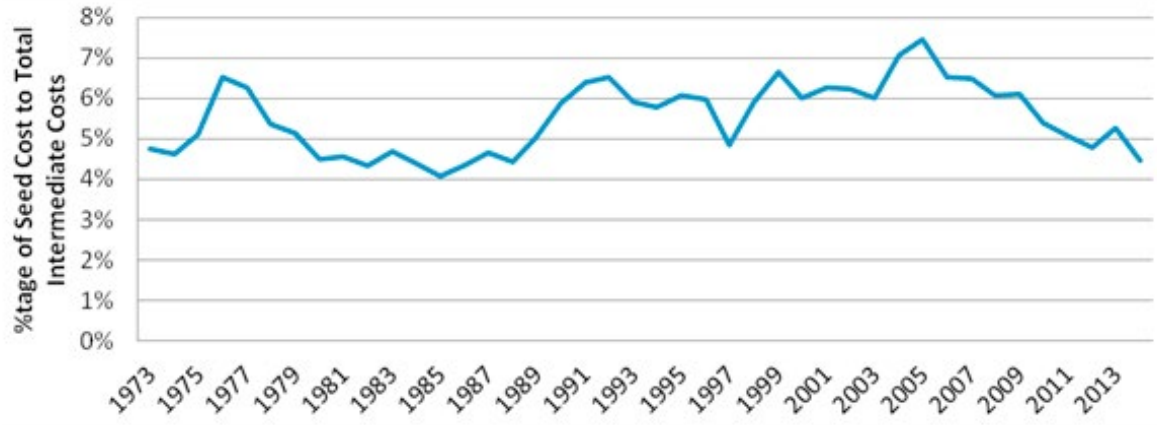
Source: Defra (2015)

Seed contributes to the overall cost structure of the farming enterprise. Much like other inputs these fluctuate over time. Figure 4.15 and Table 4.14 shows the proportion of seed cost to total farm production and related costs (known as intermediates, which includes such items as energy, fertiliser, and plant protection, as well as machinery repairs and other costs). Contribution to costs from seeds tends to remain at around 5-6% over the whole period

6 No-one has estimated the effect of concentration on seed prices in the UK. Several studies in the US do find a positive relationship between increasing concentration and seed price.

(energy is the largest contributor to total intermediate costs). However, it should be noted that intermediate costs have tended to rise over the last decade. This means the cost of seeds has risen in line with price rises for intermediates.

Figure 4.15. The proportion of seed cost to total intermediate costs from 1973 to 2014.



Source: Defra (2015)

Table 4.14. Descriptive statistics of contribution of seeds to overall farming costs

	73-84	85-94	95-04	05-14
Mean	5.0%	5.3%	6.1%	5.8%
SD	0.7%	0.9%	0.6%	0.9%

4.4 Barriers to entry and cost of entry

Barriers to entry to UK plant breeding are high. Simply examining membership lists of the BSPB, which represent UK plant breeders, show no new entrants for the last 17 years[7]. In addition, the UK market for seeds itself is relatively small and the potential for generating sustainable returns is limited to the area of land dedicated to agricultural or horticultural production.

- **High establishment costs:** The main barrier to entry is the cost of establishing and maintaining a commercial plant breeding programme. Plant breeding is a highly research intensive process, requiring capacity through scientific staff and capital investment in facilities for identifying and extending particular traits. The level of continual investment required to maintain a breeding programme varies, but has been estimated at the upper limit of £1.5 to £2 million per year, and at the lower limit of at least £200,000 per year for just a few lines. Micro level plant breeders do exist who have had some success on the market. These companies tend to have small numbers of lines which are maintained at reduced costs.

7 Personal Conversation with Penny Maplestone (BSPB)

- **Long-time lag: Establishing** a variety onto the National List requires at least 5-15 years of development and testing. This infers additional maintenance costs for marketing and protecting the variety to ensure a return to the investment.

- **Economies of scale:** Breeding programmes can be large and breeders make a selection of the most promising lines based on future demanded traits and climatic conditions. Although a variety could be introduced further testing is needed to qualify that variety for the Recommended List. Recommended List status is an objective assessment conducted by the AHDB and this gives growers certain indications of beneficial traits that the seeds offer. Breeders potentially deal with multiples of 10,000 crosses and lines and, out of these, 10 lines may eventually make the National List. Generally only 1 would be selected for the Recommended List and therefore prove successful in the market. Hence, these profitable lines must sustain the business and allow investment to continue which requires investment to maintain multiple lines.

- **Competing and collaborative markets:** Though there are high levels of concentration in the market leaders change over time as newer, better performing varieties are introduced. The markets that plant breeders serve are highly competitive and dominated by oligopolies who frequently share material. Consequently, opportunities for limiting prices or general anti-competitive behaviour may occur. In the US, DuPont raised an anti-trust investigation into Monsanto, accusing them of aggressive practices to maintain market position (Vector Strategy Group, 2010), though this has recently been dropped (Wall Street Journal, 2012).

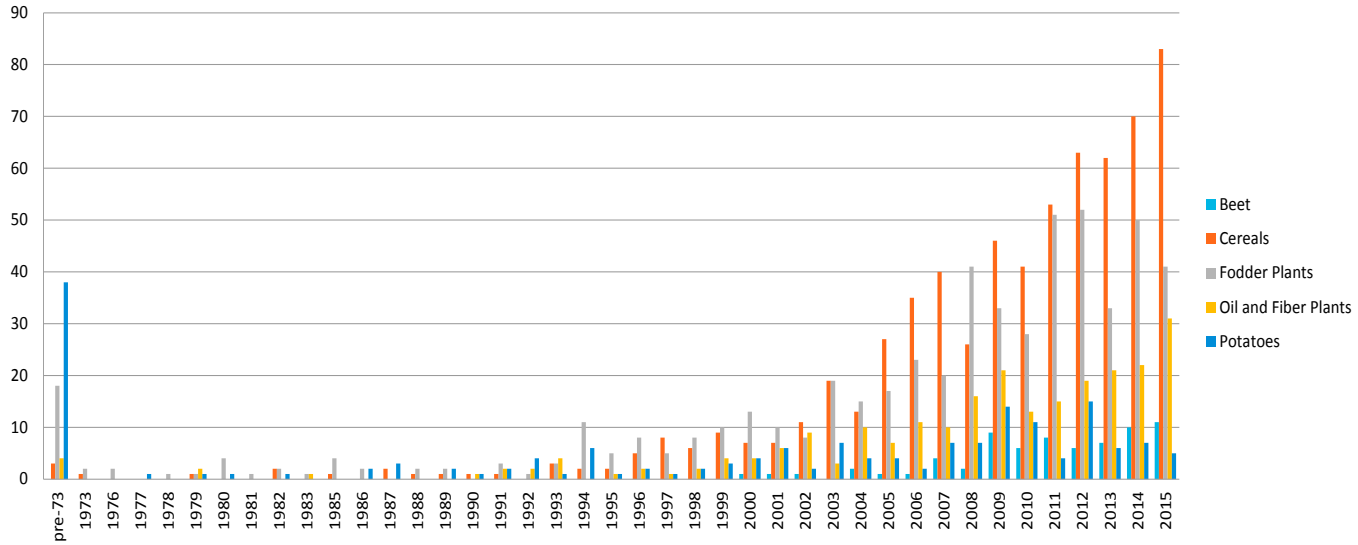
5.0. Innovation, funding mechanisms and Intellectual Property Rights

5.1. The level of new varietal development within the UK sector

The CPVO (2016) identifies the country of origin of applications for PVRs. In 2015 the Netherlands filed more than double the PVRs of the second leading country, France, which infers the significant activity within the ornamental sector and the role of Netherlands based companies in bringing forward new varieties. Across the EU, the Netherlands applied for 985 PVRs, compared to France and Germany, who applied for around 460 PVRs each. The UK, by comparison applied for 73, ranking the UK as 7th across EU. When applications from non-EU countries are included, the US and Switzerland applied for more PVRs than the UK in 2015.

The average time for varietal development is between 6 to 15 years (though this can extend in some cases to 20 years, and is dependent on plant type). The best source for understanding varietal introduction is the UK National List (compiled by APHA). A monthly gazette is produced of current varieties registered for marketing, as are the addresses of maintainers of this genetic material (APHA, 2016). An analysis of frequencies of varieties against maintainers are presented for each plant group using the latest (up to January 2016) annual gazette. Vegetable breeding has no requirement for performance testing, unlike agricultural species, so the market is much more European . Similarly for the ornamentals market there is no national listing. Consequently this exercise cannot be replicated for these sectors.

Figure 5.1. Agricultural varieties on the current national lists maintained and year registered, number of varieties



Source: Authors Calculation (APHA, 2016)

The average commercial life for a successful wheat or barley variety is around five - six years, but this can be extended for a quality malting barley. Figure 5.1 indicates that around 13% of total cereals varieties on the market were introduced in 2015.

For sugar beet there are currently 70 varieties on the list, with the earliest introduced in 2000, and the majority being introduced from 2009 onwards. In 2015, 11 new varieties were added to the list (16% of total varieties). Notably, in the sugar beet sector there is a formal system in which British Sugar purchases a certain volume of each newly recommended variety.

In the fodder sector, which includes grasses, the rate of varietal introduction is lower, with only 7% of total varieties introduced in 2015. Oil and fibre varieties tend to have a faster turnover rate (13% of total varieties introduced in 2015). Conversely, for potatoes, 116 varieties are currently on the national list. At times, including last year, only one variety was added as potatoes require a longer time to develop and this is reflected in the longer varietal protection granted (30 years). In addition, around 66% of the potatoes planted in the UK are free of PVRs.

5.2 Use of public innovation sources

The UK research system provides a number of mechanisms to encourage public-private interaction. Funding between public and private sectors are at times difficult to define on a project by project basis, as some of this is provided as 'in-kind' benefits such as the shared use of facilities or expertise. These initiatives for linkage have changed over time, e.g. DEFRA LINK mechanisms, Technology Strategy Board and the recent Sustainable Agriculture Research and Innovation Club (SARIC) run by the UK Research Councils. These are non-specific to plant breeding but have been used by plant breeders.

Another approach in the plant breeding sector is the formation of pre-competitive breeders clubs centred on a particular commodity. Examples of these include the Defra Oilseed Rape Genetic Improvement Networks and Wheat Improvement Networks, with the aim of identifying future market traits and utilising cross-working between sectors. In the fruit sector, examples exist such as the Strawberry Breeders Club. This is a consortium between the East Malling Research group and a range of industry interests across the UK and Europe with the aim of commercialising varieties identified through publically funded research (EMR, 2014).

A recent innovation is the WISP (Wheat Improvement Genetic Programme), which is a BBSRC funded collaborative initiative bringing together experts in wheat genetics and breeding from five institutions. The purpose is to understand and develop wheat strains which are resilient to future economic and societal pressures, with traits such as drought tolerance, yield growth and disease resistance. The outcome of this consortium is to make new germplasm freely available. That means plant breeders can use this germplasm to cross with their existing lines.

Main (2013) argued that the strength of maintaining a UK research base leads to investment from foreign research-intensive companies. She finds that there is overall complementarity between the needs and motivations of the public and private sectors in the life-sciences. A strong public agricultural R&D base can therefore offer both returns to scale and reduction of risk and uncertainties to encourage more technologies to be introduced. The UK plant science base is second in global rankings based on publication impact (SCImago, 2007).

The level of private sector collaboration with the public sector

A survey was conducted of major commercial agri-tech companies in 2014 with the aim of understanding research activity. Out of the 11 plant breeders who responded eight agreed that without the part-funding contribution their research and development would definitely not have been carried out. Table 5.1 shows that the companies asked did not rely on funding mechanisms aside from the Technology Strategy Board (TSB) and some research council funding.

Table 5.1. Response to did you receive part funding from any of the following UK research funders

	Technology Strategy Board (including Agri-Tech)	Research Councils	Defra	Other UK Government	EU Funding	None of the above
No	6	8	11	10	11	9
Yes	5	3	0	1	0	2

Source: ADAS et al. (2015)

In addition, companies responding to our survey identified that an average of 12% of their total R&D expenditure emerged from public funding sources. This ranged from 0% for two large firms, and up to 38% for a smaller UK based plant breeder. Moreover, the amount of expenditure on external sources to conduct the research varied from 5% up to 50%, for a smaller UK based plant breeder.

Perceptions of UK public funding sources and the public research base

When asked for key drivers for using public researchers and funding mechanisms, common responses were to either: a) bridge the translational science gap between academia and industry; or b) accommodate research expertise which is not available in-house. More in-depth answers focused on the capacity for investment needed. Two companies specified the role that the public research base has in reducing industry costs, by contracting breeding tasks or for incentivising industry to participate in R&D and innovation by reducing the investment burden. One response centred on the public sector as a means to fund R&D capital cost which are not covered by R&D tax credits.

Conversely, a range of barriers to using UK public funding sources highlighted the requirements for match funding and eligibility of institutes, alongside the risks in developing applications that may not succeed. A second tranche of barriers focused on issues of intellectual property, more specifically limits, as the responder's saw it, for exploiting the results and the propriety of material to be appropriated by the firm involved. In line with this, the BSPB offered a response to the House of Lords in 2012 when asked about barriers to commercialising public sector research:

> *'Sometimes research organisations over-value the worth of their IP; companies can be deterred from entering into collaboration with academia where the upfront demands for use of IP are unreasonable and unrealistic […..] and there is a mismatch between the understanding of the public sector research funders, some academics and the industry of what constitutes research that can be taken up and used in the commercial sector.*
>
> (BSPB Response to HoL, 2012).

Notably, they mention that the Defra LINK programme which ran for a number of years has not led to any patents in the last decade for the plant breeders. To illustrate this further their response details mismatches in belief between the public sector and the commercial sector; that is, whilst the fundamental research may be outstanding and world-leading, there is little appreciation of the downstream, more applied and development work needed to bring the technology
to market.

> *…The downstream work in taking this from discovery, through marker assisted back crossing, clean-up, seed bulking and field testing, is still required. The delivery timescales into agriculture are more like 10–12 years for simple traits and much more for complex ones.*
>
> (BSPB Response to HoL, 2012).

The BSPB emphasise that this phase, seen as the province of the commercial sector, is essential to commercialisation, but that the public funding landscape does not recognise the expense of these more mundane yet essential tasks when evaluating proposals.

5.3. Perceptions of current IPRs on determining innovation indicators within the sector

The role of plant variety rights in the business model

From the survey responses, the number of EU plant variety rights held ranged from a minimum of five, for a UK based producer of peas and beans, to 'hundreds of parent lines' for a TNC. For most companies the PVR was held solely by the parent company and a percentage of the sales royalty retained by the UK base. For one company, an equal number of PVRs were jointly owned with other breeders, as were owned in-house. For one smaller UK based breeder, most varieties were firstly placed for UK protection on the National Lists, and then EU protection was sought for the variety.

In terms of qualitative perceptions of PVRs, there was a consensus that PVRs are significantly more important than patents for the current running of the business model. This was the main source or, in the case of smaller firms, the only source of income. PVRs effectively define the objectives of the plant breeders, and the companies surveyed were agreed that they would always apply for them. One company stated that PVRs were vital and that without PVRs there would be no R&D.

The costs of PVR protection

The costs of PVR protection to each company differed and was dependant on species. At an EU level, application costs are currently around 450 to 650 Euros per variety, with an annual fee of 250 Euros for each year the rights remain in place. This does not include the cost of DUS testing (distinctness, uniformity and stability) which is a requirement for PVR for all species and for National Listing for agricultural and vegetable species. Testing may take between one to four years, depending on species. Generally though vegetable and ornamental species will need around one year, with most agricultural species needing two years. The maintenance cost is dependent on the success of the variety on the market but could continue for around ten years until the variety is no longer commercially viable (where royalty income becomes less than the cost of protection).

Accordingly, the cost per marketed variety for PVR protection will vary dependant on the size and activity of the plant breeding programme. The average time of applications for plant varietal testing was estimated to be around three years, which covers the requirements for trailing and testing to identify marketable traits. The majority of companies aimed to keep the PVR in force for as long as there were commercially viable. The costs, itemised by the companies surveyed, can be substantial, at around £700,000 per annum for a market leading TNC. For a UK based specialist agricultural breeder an average, for national list and EU protection, of around £1,000 per variety per year was estimated.

The average length of time of a PVR depends on the crop but ranged from seven years up to ten years for the companies surveyed, but these could have a maximum of 20-25 years or a minimum of 2-3 years. PVR length seemed to be shorter for vegetable varieties.

The role of patents within the business model

Generally PVRs were considered far more important currently than patents for the companies surveyed. For patent rights, traits are protected rather than varieties. Only one company claimed to have three patents in the vegetable sector. However, all companies stated they had a number of pending patents. One company identified that patents are sometimes applied for regarding novel material. Though one company clarified that:

> *'Patents are the IP tool relevant for protecting specific traits which can be comprised in many different varieties.'*

In terms of securing a return, one company emphasised:

> *'investment in the use of new technologies requires the ability to protect inventions using patents. Our business model is reliant upon freedom to operate and the breeders' exemption […] is fundamentally critical.'*

5.4. How innovation occurs within the sector

Breeding techniques used

The companies surveyed were all conducting in-house conventional crossing and pedigree breeding, as well as hybridisation. In addition, other techniques used were marker assisted selection and genotyping, and genomic selection techniques. Some of these, along with more advanced technological methods, were conducted in-house at their parent headquarters in mainland Europe. A smaller UK based company outsources genotyping to companies and universities, whereas another company used the public sector for disease evaluation work.

The extent that innovation arises within or outside the companies

An average of 89% of all plant-related research is funded internally. Averages varied from 83% for small sized breeders, 89% for medium-sized breeders and 95% for micro-sized breeders. The amount of research not funded by the company varied from an average of 5% for micro to small breeders and 11% for medium sized breeders. This may suggest that the larger companies are more frequently utilising the public-private funding mechanisms available.

Third party held material

Companies were asked the percentage of their research projects that use third party plant material. There were some extreme values ranging from 0% (for one company) to 75% (two companies). The average for micro-sized business was 40%, for small businesses this was 38% and for medium sized business this was 35%. Hence, around 35-40% of genetic material currently emerges from third party sources.

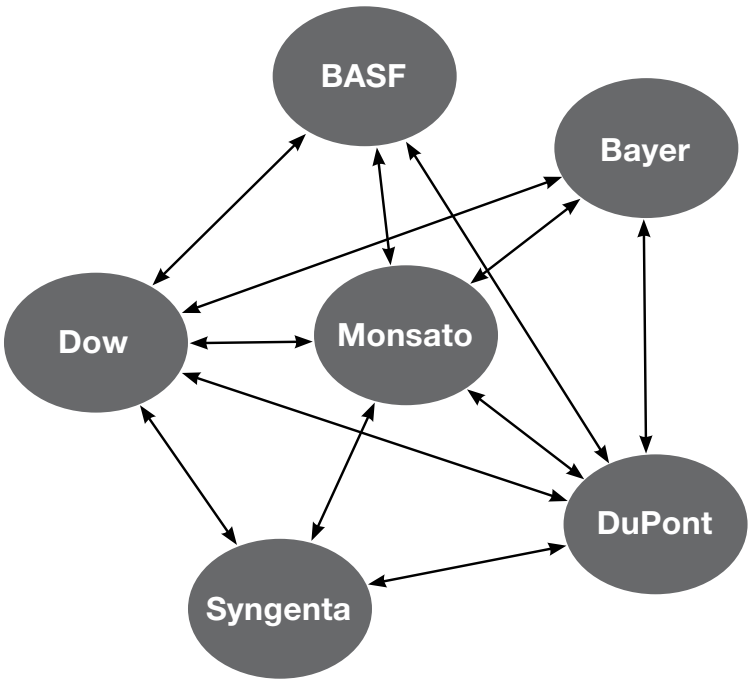
Moreover, these companies asked the percentage of plant breeding material used which emerged from collaboration with other plant breeding organisations. One company refused to answer but for the others this varied from 0% for one breeder to 50% for another breeder. Averages were 3% for micro-sized breeders, 25% for small-sized breeders and 14% for medium-sized breeders. Accordingly, around 16% of plant material used in R&D emerges from collaboration.

When asked to further identify the organisations with whom these companies collaborated a variety of commercial and public sector arrangements were identified. These included specific European based breeders, other TNCs, as well as public sector initiatives such as the Defra genetic networks[8]. A medium sized breeder stated that there is free exchange of breeding material between breeders, whereas a TNC identified cross licensing agreements with other private sector breeders, in addition to research collaborations with public research institutes and universities.

8 Currently there are a number of commodity specific genetic networks, comprised of public sector institutes and commercial breeders, e.g. for Wheat (WGIN), Oilseed (ORIGIN), and pulses(PCGIN)

5.5 Desire to innovate and collaborate between partners

A number of commercial plant breeders rely on the free movement of genetic material. This genetic material emerges from the market or is developed through public sector initiatives, such as the WISP consortium for development and sharing of wheat genetic material. A more contentious area, perhaps, is the swapping of genetic material using cross-licensing agreements. Howard (2015) notes that these occur particularly for transgenic crops in the US and equates this cross-licensing as a form of monopoly or cartel formation. The graph below illustrates this as a 'web' of cross-licensing agreements within the traditional 'big six' breeders.



Source: Howard (2015)

This level of activity could be conducted at an EU level, with consequences for the UK sector. Unpicking these relationships is difficult, but Ragonnaud (2013) identified the following:

> *'Cross-licensing agreements, in particular for transgenic seed traits, have created a network of relationships between seed companies. These agreements have increased with the development of adding multiple transgenes in crops. As stated by Monsanto in its 2012 annual report "With the exception of competitors in our Seminis and De Ruiter vegetable seed business, most of our seed competitors are also licensees of our germplasm or biotechnology traits"'*

> *Another example is the license and cooperation agreement signed in 2011 between RAGT, Semences and Bayer Cropscience, granting Bayer access to winter wheat germplasm and*
>
> *associated molecular markers from RAGT. Furthermore, RAGT may license wheat traits from Bayer'*
>
> Ragonnaud (2013, pp 15)

It could be argued that offering licences for material between companies has benefits, as it releases material for others to develop new varieties. However, it is difficult to identify the limits that these licences impose on use of genetic material. RAGT have a presence in the UK cereals market, but it is also possible that the more prominent market leaders, such as KWS and Limagrain, would also engage in these cross-licensing agreements, in particular because these two companies formed Agreliant, which develops GM corn for the North American market[9]. The details of these licences are commercially sensitive and therefore it is difficult to fully determine the extent to which these licences may encourage or inhibit innovation.

Within our survey companies emphasised the cross-border issues of plant breeding, as some of the breeding is centralised, but informed by testing and development work within the UK research base. Collaboration occurs at the technical level. One company stated:

> *'…we centralise all these activities either alone or in association with others in order to amortise cost and use equipment and staff efficiently. Although we run a […] breeding programme in the UK this is carried out on behalf of another plant breeding company. We charge for this service, but have no income from any successful varieties produced from this programme.*
>
> *In another crop […] there is often dual ownership of material with a mother line owned by one company and father line by another. Royalty income has therefore to be split with these owners. […] Whilst this can help to produce successful material, it does result in reduced royalty income.'*

There was some consensus that the recognition of intellectual property is crucial for the continuation of plant breeding activity and, as technology develops, the 'intellectual property' may consist of validated molecular markers for different traits. This aids genotyping within the plant material. Given the discussion above concerning cross-licensing arrangements between companies it will be more difficult to monitor and identify ownership of the material.

One company stated:

> *'For the sustainable investment in breeding and plant research and delivery of new varieties to the marketplace for the benefit of agriculture and Food Security, we need co-existence between PVRs and Patents. In addition, we need to have access to Plant Genetic Resources to ensure availability of necessary genetic diversity for developing new improved varieties that are suitable for the current and future environmental conditions that exist.'*

9 http://agreliantgenetics.com/history-ownership/

Whereas another stated:

> *'We participate in the free exchange of material to others to incorporate in their breeding programmes we believe in the breeder's exemption in this respect. This should apply whether or not material is protected by patent or PBR.'*

Consequently, this may allude to the fact that intellectual property may be an enabler or, equally, a barrier to development of research within this sector. This seems to be dependent on the market position, and the size and strength of the research base of each company involved in plant breeding.

6.0. Summary

1. The size and shape of commercial UK plant breeding

The UK commercial plant breeding industry serves agricultural, vegetable and ornamental markets. The UK market for commercial agricultural and vegetable seeds is dominated by trans-national corporations (TNCs) who conduct or co-ordinate research through UK subsidiaries, but also UK companies who serve a range of markets. Based on research staff employed and turnover alone, all plant breeders within the UK market (whether UK based or subsidiaries of TNCs) are SME's.

The UK market for seeds is relatively small, compared to France or Germany, and the UK is a net importer of seeds. The UK exports around £125 million worth of seeds which serve a number of other EU and non-EU markets. The main imports emerge from the European mainland which harbour global leaders in plant breeding such as KWS, Syngenta and Limagrain. Whilst the GM Seeds Inspectorate record some information for certain seed types imported, these are not publically available, hence data on country of origin of imports are not available.

We could identify around 23 agricultural and vegetable plant breeders, 11 of which conduct serious plant breeding programmes. A caveat to the findings of the report is the lack of information concerning the ornamentals sector. The ornamentals market, which holds the majority of plant variety rights (PVRs) in the UK, is more fragmented and consists of numerous breeders of single varieties using traditional breeding techniques. This is quite a polarised industry in terms of business models as these breeders may or may not apply for EU PVR protection. Hence, whilst we could identify 13 larger ornamental breeders which are UK based or subsidiaries of a TNC, there are numerous small breeders who could not be identified as they are not members of breeding societies or may not apply for PVRs. Perhaps because of this fragmentation there was no engagement from the ornamentals sector in our survey. This is compounded by the lack of secondary data collected on the size, structure and economic importance of this sector.

Plant breeding covers a range of techniques, but at the commercial end the practice of plant breeding is highly research intensive, requiring both staff and facilities to manage numerous lines of genetic material to produce marketable varieties. Accordingly, barriers to entry are high and breeding programmes are usually purchased as part of acquisitions within the seed breeding sector, rather than established. Nevertheless, some agricultural markets are served by smaller UK plant breeders. This may indicate that management of a few lines and specialisation into a particular crop may offer entry into the market.

2. Importance of UK plant breeding industry to UK economy

Plant breeding activity within TNCs tends to be distributed across a number of countries. In addition, these corporations tend to conduct both plant breeding and agro-chemical activities. Hence, it is difficult to separate these activities at a UK level to determine direct economic contribution. Using responses from two surveys, which cover agricultural and vegetable

breeding companies, we estimate the annual turnover from UK plant breeding to be in the region of £200 to £230 million, with R&D expenditure estimated at around £30 to 40 million. This figure does not include capital spend which may include one-off expenditures on greenhouses etc. In addition, we estimate just under 400 employees directly employed in research and technical activities within these companies. This will be dwarfed by the marketing and administration functions in a number of TNCs, which are not accounted for here.

Seeds are usually sold on a per tonnage basis and therefore growth in the UK sector is limited to land dedicated to a particular crop. This in turn is determined by the prices expected from these markets. Prices for agricultural products vary on a year to year basis and farmers purchase their seeds on market prices expected. The market potential therefore varies annually. Larger breeders can also diversify into a range of markets to negate some of this risk.

3. Indirect importance of plant breeding sector to UK economy

The indirect benefit of genetic improvement from plant breeding is estimated to be substantial through yield and quality improvements and resilience to changing climate. The food supply chain contributes 7% of gross value added to the UK economy (£109 billion) and most of this, whether crops or animals, is underpinned by plant and grass breeding. European mainland and Non-European plant breeders with no UK base are present in most crop markets. Consequently, the value of benefit from UK plant breeding would be lower if we could fully exclude seeds from non-UK based plant breeding.

The reliance on imports in seeds indicates that the UK benefits from genetic improvement from mainland Europe and from non-European countries. It is difficult to breakdown where seeds are imported from but for some commodities, such as forage and oilseeds as well as flower seeds, imports are dominant France, Germany and Switzerland are the main bases for agricultural and vegetable plant breeding and would be expected to deliver seeds which improve performance for UK growers in the cereals, vegetables and oilseeds markets.

The UK is almost totally reliant on imports of cut flowers and ornamentals, aside from nursery bedding plants, and Holland is the main innovator with respect to this market. In addition, numerous varieties of potatoes are developed by Dutch breeders. Non-EU countries, through TNCs such as Monsanto, will supply seeds for a range of markets, but are particularly dominant in oilseeds. Recent proposals by ChemChina to buy Syngenta may, in the long term, lead to imports of seeds which benefit from Chinese research activity. Accordingly, whilst the institutional structure of UK plant breeding is important to UK growers, it may be that international systems of governance and non-UK innovation mechanisms will be significant in maintaining or improving performance for UK markets.

4. The business models of plant breeders

The business models of plant breeders revolve around applying and securing PVRs. For a number of breeders this is the sole source of income and is needed to sustain the numerous

lines which fail to reach the market. Most companies will pursue protection at the EU level for the life of profitability of the variety. In addition, most of the breeders surveyed were utilising patents or applying for patents which relate to techniques appropriate for a range of varieties.

The Community Plant Variety Database shows there are currently 1,249 PVRs in force for the UK and 205 holders of grants. The ornamentals sector has the majority of PVRs in force, (835 or 66% of the total PVRs). Fruit and vegetable varieties have 219 PVRs (18%) with the remaining PVRs (15%) related to agricultural crops. There is less information held on patents by UK plant breeders, but of the breeders we surveyed all were holders of patents or were in the process of applying for patents.

The plant breeders themselves argue that the recognition of intellectual property is crucial for the continuation of plant breeding activity in the UK. It is important to note also that as technology develops the 'intellectual property' may consist of validated molecular markers for different traits. This may be more difficult to monitor and identify ownership of the material. Utilising and benefiting from IP may therefore be dependent on the market position, the size and strength of the research base of each company involved in plant breeding to exploit these techniques.

The average time for varietal development can be between 6 to 15 years (though this can extend in some cases to 20 years, and is dependent on plant type). For agricultural seed, where reliable data exist, around 10 % to 15% of total varieties maintained on the National List were introduced in 2015.

5. How does innovation arise?

Given the transnational structure and co-ordination of research across countries it is difficult to determine the amount of innovation occurring within the UK that leads directly to UK produced seed. Examination of plant breeder's histories identify five UK owned plant breeders which cover micro to medium scale businesses serving UK and international markets. These companies breed seed for potato, barley, oilseed and grass and forage markets, as well as providing vegetable varieties. In addition, around 90 other mostly UK companies maintain the supply chain by selling seed to producers and growers.

Genetic material, the main input into plant breeding, is available for development and also supplied by the public sector. As an estimate, around 35% to 40% of third party material is used by UK plant breeders to develop new varieties. Most TNCs have cross-licensing agreements[10]. This may be to share parent lines where authorisation is required for repeated use to produce another variety, in order to gain the benefit of producing hybrids from genetically diverse parents (one example of this is oilseed rape in the UK).

The strong public UK research base in plant breeding provides an incentive for commercial investment and may have incentivised TNCs to keep subsidiaries in the UK. Most commercial plant breeders rely on the facilities and expertise provided by the public sector to accommodate the economies of scale needed to develop new varieties.

10

There is some engagement of commercial plant breeders with funding initiatives, such as TSB grants and Defra LINK. However, a disincentive to commercial plant breeders is that the investment required for commercialising public innovations may be underestimated. Related to this it seems that UK subsidiaries of TNCs are more heavily involved in public-private initiatives than UK breeders. As research is co-ordinated across countries it is difficult to determine the level of spill-over from UK public R&D expenditure which benefits non-UK markets. Nevertheless, returns are estimated to be high for public investment into UK plant breeding, but an increased focused on how to commercialise results from world leading public research should lead to improved internalisation of returns for the UK economy.

6. Current levels of competition in the plant breeding sector.

The market for varieties appears to be highly competitive, with healthy replacement of market leaders occurring over sustained periods. Within the agricultural sector this is evidenced by changes to the Agricultural Horticultural Development Board (AHDB) Recommended Lists for cereals and oilseeds. These offer detailed information of performance between market leaders and substitutes and infers low switching costs for farmers between different varieties. Smaller UK breeders, such as Mike Pickford Seeds and Blackman Agriculture Limited do maintain a portion of the market within agricultural crops.

Rivalry in the sector is high but larger companies may have agreements in force which licence material and technologies between different companies. **This could lead to anti-competitive behaviour if licences are not widely available and so restrict access to breeding material.**

Moreover, patents related to techniques, apply to numerous varieties and restricting these processes may limit the ability of rivals to innovate to produce newer material.

7. Seed prices and farm saved seed

Due to the high level of investment, the management of multiple lines and long pay-off periods, some markets are highly concentrated. Though its contribution to overall input cost has remained static the price of seed, along with other inputs, has doubled in real terms since 2000. This may be due to concentration of plant breeding, but a significant factor will be the exchange rate affecting the cost of inputs.

Given the fractured nature of the farming industry and the competitive nature of markets, most growers have the choice of a range of varieties from a number of companies. In addition, there are various additional mixtures, such as hybrid or dressed (where agricultural chemicals are already integrated into the final product). The farmer tends to buy seeds through regional agents and the most intensive cropping areas in the UK are served by a number of seed merchants, which will allow some flexibility for switching varieties.

A farmer will aim to produce for a particular market. The AHDB Recommended Lists will identify the particular traits which will meet quality standards required by the buyer of the grown product. As such this may restrict choice for the farmer but this is dictated by end

users of the final product, rather than breeders and sellers of seed. In addition, the farmer chooses the amount of farm saved seed (FSS) to plant for the second season. A number of firms offer quality assurance checking and dressing of farm saved seed. This adds to the cost of using the seed but may ensure some parity of yield with fresh bought seed.

The amount of farm saved seed tends to reflect the economic position of farmers. Dependant on the commodity rates of FSS planted vary from 35% to over 50%. Similar rates of FSS occur across most EU countries, though administrative systems differ in their adequacy for collecting royalties. According to the BSPB (2015) FSS contributes to around a third of the total income available to support UK breeding programmes. Clearly a reduced royalty from seeds will be a disincentive to innovate within plant breeding. However, the plant breeders benefit from the organised royalty collection system in the UK and this may be an incentive to continue to invest in the UK, compared to countries where royalty collection systems are inadequate or newly established.

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Appendix One: Questionnaire

Questionnaire

Assessing the UK Plant Breeding Sector and Patent Rights

Thank you for taking the time to fill in this questionnaire.

The purpose of the questionnaire is to gather: 1) data on the plant breeding sector; 2) information on plant patents and plant variety rights.

We understand some of these questions might be of a sensitive nature, but please be assured that all responses will be anonymised before reporting, unless you have expressively given permission not to do so (through the consent form attached).

You are, of course, free to refuse answering any of the questions, but we ask that you to fill the questionnaire as fully as possible, as the results of this exercise will be used to inform policy-making by the UK Intellectual Property Office.

Please return the filled questionnaire by end-of-play Tuesday, 22nd of March 2016. This is so we have time to collate replies, report them, re-distribute the reported findings for further comment and collate these ahead of the mid-April follow-up meeting (a detailed calendar can be consulted in the Consent Form).

Please feel free to contact andrew.barnes@sruc.ac.uk if you have any queries.

Section 1

	General information	
1.1	Name: Click here to enter your name.	
1.2	Organisation/Company: Click here to enter the name of your organisation.	
1.3	Where is your organisation/company based in the UK? Click here to enter the location/address.	
1.4	Is your organisation/company active outside the UK? If so, what is its geographic coverage? Click here to enter your reply	
1.5	Can you indicate your parent company (if applicable) and where it is based?# Click here to enter the name of the parent company and its location.	
1.6	What of the following primary activities does your company engage in? *Select all that apply*	☐ Seed multiplier ☐ Plant breeding ☐ Crop trials ☐ Partner in public funded research ☐ Other: Please specify here.

Section 2

	Economic Contribution
2.1	What was your approximate turnover for UK operations in 2015? Enter figure in numbers only, along with its respective unit (e.g. £, £m, €) And what was your average annual turnover for the UK for the last 5 years? Enter figure in numbers only, along with its respective unit (e.g. £, £m, €) Do you feel the returns from the UK based operations allow you to sustainably re-invest in plant breeding R&D? Choose an option from the drop-down menu. Please explain your choice here.
2.2	How many people do you employ in the UK? Click here to enter number.
2.3	Relating to R&D spend: R&D spend includes any: • Internal spend on in-house R&D and any spend on external services for R&D (e.g. to • universities, private R&D organisations that are based in the UK); • Spend by the organisation where this may also be supported by public funding (e.g. Innovate UK or EU Funding); • Resources needed to make the R&D happen, including in-kind costs to projects (i.e. labour costs, overheads, capital equipment, travel and subsistence and all capital paid to other organisations. • The R&D spend figure excludes: • Education and training; • Science or technological activities not for the direct purpose of an R&D project, such as attending scientific conferences or patent services; • Business activities not for the direct purpose of an R&D project; • Finance or support of R&D to other organisations for R&D not relating to your own company (please include your own R&D contracted out to other organisations); • Finance or support of R&D to other countries (including financing R&D for your own company outside of the UK).

Please indicate your approximate private annual spend on R&D related to plant breeding and trialling in the UK:

a. in 2015:

Click here to enter figure either as percentage of turnover or as a number along with its respective unit (e.g. £, £m, €)

b. as a 5-year average:

Click here to enter figure either as percentage of turnover or as a number along with its respective unit (e.g. £, £m, €)

As a percentage, how much of this R&D is approximately:

c. internal spend/in-house research? Click here to enter percentage

d. funded by other UK research institutes? Click here to enter percentage

e. spent on external services by other esearch organisations? Click here to enter percentage

2.4 If your R&D spend figure includes substantial capital expenditure (such as lab facilities, glasshouses and equipment) could you please specify:

Click here to enter explaanatory notes

2.5 For which crops does your company develop R&D? Select all that apply.

Colour Type	Number of varieties your company has in the market	Market share (as % of total market sales)
☐ Barley	Enter number here	Enter percentage here
☐ Wheat	Enter number here	Enter percentage here
☐ Grasses	Enter number here	Enter percentage here
☐ Oil seed rape	Enter number here	Enter percentage here
☐ Potatoes	Enter number here	Enter percentage here
☐ Vegetables	Enter number here	Enter percentage here
☐ Other. Please specify.	Enter number here	Enter percentage here
☐ Other. Please specify.	Enter number here	Enter percentage here

2.6	What is the average time frame for development of these varieties? And does it vary by crop type? This question aims to capture the dynamism of plant breeding activities. Please reply in as much detail as you can
2.7	What do you see as the main steps (after research is completed) in the process of getting a researched variety to market? Click here to enter text. Click here to enter text

Section 3

	Patents and Plant Variety Rights
3.1	What role do patents and/or plant variety rights (whether the right is held by yourself or others) play in your business model? Click here to enter text. Click here to enter text
3.2	Can you give a figure for the number of plant variety rights you currently hold for plants that are commercially available in the EU, broken down by crop type. Click here to enter number per crop. Click here to enter number per crop
3.3	Can you give a figure for the number of patents (granted and in force) you currently hold which protect commercially available plant varieties available in the EU Click here to enter number per crop. Click here to enter number per crop

3.4	How many patent applications do you have pending that include claims directed to plants that could be currently marketed in the EU? Click here to enter number per crop. Click here to enter number per crop
3.5	What is the cost of services for patent protection (whether your own or not) and plant variety rights? If necessary, add explanatory notes indicating how costs are split between different aspects of the process. Click here to enter text. Click here to enter text
3.6	Do you have any views about patent transparency in the plant breeding sector and the ease of patent licensing? Click here to enter text. Click here to enter frequency per crop type
3.7	What is the average frequency by which you apply for a patent (per crop)? Click here to enter frequency per crop type. Click here to enter frequency per crop type
3.8	How long do you keep any patents or plant variety rights in force and what are the reasons for so doing?Please indicate maximum, average and minimum lengths of time. Please indicate maximum, average and minimum lengths of time

Section 4

	Innovations
4.1	Please list the plant breeding techniques you: (i) currently use: Click here to enter text (ii) plan to use in the future: Click here to enter text Please indicate what is outsourced.

4.2	As a percentage, how much of your plant-related research: a. Builds on internal investment and development: b. Relies on public sector research not funded by the company:	Click here to enter percentage Click here to enter percentage
4.3	What percentage of your research projects requires the use of third party held plant material?	Click here to enter percentage
4.4	What is the percentage of plant breeding material used by your company that emerges in collaboration with other plant breeding organisations? If possible, please indicate with which organisations you have established this type of collaboration:	Click here to enter percentage Click here to enter text

Section 5

	Final remarks

CONCLUSION

Thank you very much for your participation and your time.

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