Report on the

Challenges and opportunities brought about by genetic diversity in the Scottish Potato Sector

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Executive summary

Potatoes are one of the most important crops in Scotland, providing a buoyant export market and an important dietary staple. As genetic agrobiodiversity is generally considered as important for the resilience of agricultural system, this research aims to understand some of the complexities of the potato sector to ensure that it is best placed to take advantage of opportunities, manage challenges and create resilience. More specifically, this research examines: i/how genetic resources are managed in the potato sector; ii/ stakeholders' perceptions of the challenges and opportunities brought about by genetic agrobiodiversity as well as, iii/their perceptions of the role played by genetic agrobiodiversity in the resilience of the sector. This will help highlight the key nodal points upon which to act in order to enhance the benefits of genetic diversity to the Scottish potato sector. A total of 18 qualitative interviews were conducted with key representatives from the sector which were transcribed for further content analysis.

The main results of this research are:

- Genetic diversity in the potato sector is relatively low as most of the commercial varieties are from the *Tuberosum species*
- Current management of the genetic agrobiodiversity is done within the framework of international treaties and a national infrastructure that guarantees the quality, health status and uniqueness of potato varieties
- The Commonwealth Potato Collection (CPC) is a key asset to the industry which potential remains to be unlock through use and diffusion of new genetic engineering techniques
- The potential of the CPC lies in the opportunities it offers to tackle challenges such as climate change and evolving phytosanitary constraints at the national and global level
- Current power structures within commercial supply chains and marketing strategies might hamper the potential brought about by agrobiodiversity
- Resilience of potato sector was seen as resulting from: environmental factors, social capital, structure of the supply chain and business models of the individual farms, market demand and offer, technological progress and political factors which interplay complexifies the sector's ability to thrive but the potato sector was judged to be resilient overall

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Introduction

As most of the world's population considers wheat, rice, maize and potatoes as everyday staples the global food system is reliant on a restricted number of crops. The challenges brought about by changes at a global scale, such as climate change, outline the importance of agricultural biodiversity for the resilience of agro-systems throughout the world. Agricultural biodiversity is defined as "the diversity of crops and their wild relatives, trees, livestock and landscapes" and recognised as "a source of nutritious foods, which are culturally acceptable and often adapted to local and low-input agricultural systems. It is also a source of important traits for breeding stress-tolerant, nutritious crops and animal breeds". (Bioversity International, 2016).

Potatoes are one of the most important crops in Scotland, which accounts for 22% of the total production in the United Kingdom. At a European level, Scotland is recognised for the high quality of seed potatoes which are produced mainly for export markets (60% to England and 40% overseas). A key asset to the Scottish industry is the availability of genetic resources existing in the Commonwealth Potato Collection (CPC) and unlocking its potential could be a major driver of change for the industry. For that purpose, this research aims at understanding: i/how genetic resources are managed in the potato sector; ii/ stakeholders' perceptions of the challenges and opportunities brought about by genetic agrobiodiversity as well as, iii/their perceptions of the role played by genetic agrobiodiversity in the resilience of the sector. This will help highlight the key nodal points upon which to act in order to enhance the benefits of genetic diversity to the Scottish potato sector.

Material and methods

We conducted 18 semi-structured interviews on the *Drivers of the Genetic Diversity in the Potato Sector*. The interviews covered topics such as; the factors that have impacted the resilience of the potato sector over the last fifteen years, the role of genetic diversity in alleviating those impacts, stakeholder networks and the impact of those networks on the breeding and growing of potato varieties. The informants belonged to the commercial potato sector (both organic and conventional) as well as the non-commercial potato sector (allotment gardeners and individuals with a particular interest in potatoes). The informants were purposively selected to represent stakeholders from breeding in the laboratory to the marketing of potatoes. The interviews were recorded and fully transcribed for qualitative analysis using the NViVo software. The interviews were coded by themes and content and relational analysis was performed under the themes which were: collections, resilience, governance, varieties, diversity, challenges and opportunities. While the content analysis aims to understand informants' vision of the concepts and phenomenon studied, the relational analysis aims to understand the relationship between those concepts.

A foreword on the genetic diversity in the potato sector

When considering genetic resources in the commercial potato sector, it is important to clarify that most of the genetic selection performed in the past decades has involved the *Tuberosum species.* To that regard, the genetic resource base is presently relatively narrow at present.

"You have genetic diversity within Tuberosum, but… if you compare that diversity to other species, what you have is very similar (…). The Commonwealth Potato Collection is hundreds of different species. So you can imagine that there's much greater diversity within the CPC than there is within all the commercial potatoes" (#01[1]).

"Most of the breeding that has been done so far has been done within the same Tuberosum species, so in those terms, the genetic diversity within the commercial potato sector is very narrow" (#01).

Therefore, in this note, genetic diversity will be considered as intra-species diversity (i.e. diversity within the *Solanum Tuberosum sp.*) when looking at the dynamics within the commercial sector as well as inter-species diversity (i.e. that extends beyond *Solanum Tuberosum sp.* to include other Solanum species) when discussing the role of gene banks such as the Commonwealth Potato Collection (CPC).

"The CPC is distinctive in that genetically, it's much more diverse probably than any collection" (#07).

If breeding realised within the same *Solanum Tuberosum species* can lead to potato clones that have similar characteristics, it is also worth mentioning that potato varieties selected that way can also have distinguished phenotypes (or visible characteristics) that result for example in distinct yield potential, disease and pathogens resistance, shape, colour, cooking characteristics, texture and taste.

Governance of the genetic resources the genetic resources in the potato sector

Collection of potato varieties

Different potato collections exist within the UK that are repositories of genetic resources for conservation, breeding and growing. In Scotland for instance, there are the Commonwealth Potato Collection (CPC), private companies' breeding collections as well as private individuals' collections.

The Commonwealth Potato Collection (CPC) and the SASA collection

The CPC comprises around 1500 accessions of about 80 wild and cultivated potato species. Each accession traces back to a handful of berries or tubers from potato plants in South or Central America, gathered from the wild or obtained from a grower at a market[2]. Such genetic resources are priceless, comprising the basic resource for the improvement and adaptation of the world's fourth most important food crop. The genetic material in the collection has made a major contribution to the potato crop worldwide and continues to do so today. The collection is maintained by the James

[1] # followed by a number refers to the informant's identifier code
[2] Source: https://www.hutton.ac.uk/about/facilities/commonwealth-potato-collection

Hutton Institute which task is to maintain this material, to make it available to researchers, breeders and educators under terms consistent with the international treaties that govern the use of such germplasm.

The CPC and the SASA (Science and Advice for Scottish Agriculture) collections have different statutory roles. The CPC role is to maintain the existence and accessibility of genetic resources that have been gathered throughout the years while SASA is the Certifying Authority for the Seed Potato Classification Scheme and also carries out a range of scientific activities in support of seed potato classification in Scotland. (https://www.sasa.gov.uk/seed-ware-potatoes). The genetic material present in the SASA collection and in private breeding companies' collections is identical as the multiplication process is a vegetative one (tubers are replanted from one year to another).

Commercial breeders

Independent breeders have their own collections and relatively little link to the Commonwealth potato collection. Because of the cost of maintenance, commercial collections are not necessarily maintained for as long as the CPC collection.

Maintenance of the genetic resources

The role of the government in maintaining the potential of the pool of resources has been highlighted. This role is to ensure genetic reserves are preserved and made available for the greater good and that decisions regarding the conservation of varieties do not prevent tackling future challenges.

'It's impossible for any one person, especially a civil servant to make judgments about which varieties are worth keeping and which are not. And so the only option for them is to maintain them all. What somebody might come along and want out of that collection now might be different from what someone might want in 20 or 50 years time out of that collection. So... it's very difficult for the government to make up the policy or to try to make up rules as to what makes a variety worth keeping in a collection or not'.

Beyond the maintenance and conservation of genetic resources, their use and exchange for breeding purposes is regulated by a number of instruments and rules detailed below.

The exchange of genetic material between collections and breeders

A number of statutory instruments regulate the exchange of genetic material between organisations. Among the instruments cited by respondents are the Plant Varieties Act 1997 and Material Transfer Agreements (MTA). At the national level, the Plant Varieties Act 1997 sets Plant breeders' rights, the scope of their rights and the duration and transmission of plant breeders' rights[3].

"And because of the Plant Varieties Act, you could ask me for samples of a variety (…) and I will share that with you because there is an open sharing arrangement that all tied in the Plant Varieties Act" (#12).

[3] Source: http://www.legislation.gov.uk/ukpga/1997/66/contents accessed [22/03/2018]

A Material Transfer Agreement (MTA) can be signed between two organisations. It is a contract that governs the "transfer of tangible research materials between two organizations, when the recipient intends to use it for his or her own research purposes. The MTA defines the rights of the provider and the recipient with respect to the materials and any derivatives"[4]. Material Transfer Agreements exist that regulate the exchange of material between for instance, the James Hutton Institute and the James Hutton Limited and other private breeding companies. When asked about the exchange of genetic material between breeders and companies, informants mentioned that genetic material was available for exchange for breeding purposes based on common agreements and/or on reciprocity but never involving monetary transactions. In that regard, it seems that there is a coordinated and collaborative effort to conserve and improve material: *"The Industry collaborates quite well in that regard" (#08).*

The movement of varieties from the breeding company or collection to the market: the Nuclear Stock Production and the Varieties Conservation Lists

Varieties which are intended for seed potato production in Scotland must be entered for Nuclear Stock Production (SASA). SASA, emanates from the Agriculture, Food and Rural Communities Directorate. It is the organisation that maintains the Nuclear Stock. Every time someone wants to introduce potato material or a new type of seeds, it must be entered into the Nuclear Stock Production where it will be tested for the presence of diseases and PCN (potato cyst nematode). Only when test results are negative will the new material be authorised for multiplication and growing in Scotland[5]. The scheme through which seed potatoes are judged able to be multiplied in Scotland is the Scottish Seed Potato Classification Scheme. SASA also has a role in ensuring the uniqueness of a given variety and that the name of a variety matches a specific set of genes.

In order to sell a new variety to the market (whether this variety results from breeding or is imported into the United Kingdom), it is initially added to the UK conservation list for marketing in the United Kingdom, and to the European Conservation List for marketing in Europe. Any offender to this obligation can be prosecuted[6]. The national lists are maintained by the Plant Variety Rights and Seeds Office (PVS), which is part of the Animal and Plant Health Agency (APHA). To be registered on those lists, proof is required that a variety is Distinct, Uniform and Stable (DUS) and that it has Value for Cultivation and Use (VCU). The varieties from the Commonwealth Potato Collection are not on that list. They are used primarily for breeding purposes.

Property rights and dynamic of potato varieties on the market

As the breeding process requires a lot of resources both in time and money the property rights are retained for a period of 30 years. A number of varieties are free of rights such as the historic Maris Piper, Maris Peer and King Edwards. These varieties remain widely popular with farmers as they are highly valued by consumers. Establishing new varieties for the market remains challenging as they

[4] Source: Wikipedia, accessed [22/03/2018]
[5] SASA, date unspecified. Seed Potato Nuclear Stock. Production and Classification in Scotland. The Scottish Government. 5p + appendices.
[6] Source: Guidance. Add a new plant variety to the national list. The Scottish Government, available at: https://www.gov.uk/guidance/national-lists-of-agricultural-and-vegetable-crops

must demonstrate novel attributes to existing varieties that already have the majority of the market shares.

Stakeholders' perceptions of the opportunities and challenges brought about by potato genetic resources and their management in Scotland

A number of key opportunities and challenges related to potato genetic diversity were highlighted by respondents. Among the opportunities cited were the richness and diversity present in the Common Wealth Potato Collection (CPC), the potential it provided for the sector to adapt to current and future challenges at the global level as well as for opening new market opportunities both at the national and international levels. Additionally, progress made in the field of genetic research such as new screening and gene editing technics were identified as key drivers of change for the sector. Challenges identified were market forces preventing the ingress of new varieties with potentially interesting characteristics, power structures and strategies implemented by key supply chain actors resulting in hampering the potential of potato agrobiodiversity, the under provisioning of human resources in potato breeding that limits the valuation of the existing agrobiodiversity, the slow diffusion or uptake of the latest progress in genetic research and technics available and current breeding objectives that fail to reflect the full potential of current genetic resources.

The opportunities and challenges are further discussed below in order to highlight the interconnections between them and the current constraints that may hamper the potential generated by genetic resources which can be considered key leverage points to be addressed further in order to unlock their potential.

The Commonwealth Potato Collection: a rich collection of landrace species with a potential to be explored and valued further

The Commonwealth Potato Collection (CPC) represents a great source of varieties that can be used to face future challenges in relation to changing environmental conditions such as climate change, the evolution of pests and diseases or to bring about novelty on the market.

Among traits that can be further exploited are drought resistance as well as pests and pathogens resistance. As such, it provides a huge potential to tackle future challenges and build up resilience with the use of new technics such as gene editing.

'The one thing to stress with the CPC it's a tremendous resource, there's so much diversity that we haven't tapped into yet, haven't been able to tap into yet. It's now with the technology that we can (…) I mean I talk about disease resistance only but there's heat stress, there's drought stress, there's…frost tolerance. (…) these potatoes grow on every continent apart from Antarctica. So, it has a lot of adaptation in the wild. We are just taping into it [this diversity]' (#03).

As new genetic engineering methods and technics become available, making sure that all the accessions are conserved to meet future needs is seen as essential and that choices made today in terms of conservation do not hamper or outweigh future opportunities.

'It is impossible for any person (…) to make judgments about which varieties are worth keeping and which are not. And so, the only option is to maintain them all. What somebody might come along and want out of that collection now might be different from what someone might want in 20 or 50 years' time out of that collection. So… it's very difficult for the government to make up the policy or to try to make up rules as to what makes a variety worth keeping in a collection or not' (#8).

Currently, the potential of the CPC is in enabling researchers to answer challenges at the national and international level, therefore helping to address global food security and opening new markets for the Scottish breeding and seed industry.

'Potato is spreading, it's range is increasing. So, it's being grown in places… now… 20 years ago China was nowhere in potato agriculture, now it's the number one. Now it's the number one producer. So of course, there are a lot of regions in China where it's quite hot, or it's very dry, the same with Africa. East Africa especially, there are a lot of potatoes grown from Ethiopia, all the way down to Kenya, South Africa, so getting potatoes that are more tolerant of drought and heat is quite important' (#13).

At the national level, it is seen as a source for product innovation through the incorporation of traits of interest for consumers.

'I think…it's quite a good diversity of potatoes in the supermarkets. It could still be better I think, I think some of the more novel stuff, like some of the material we're working on experimentally I think which has quite good attributes for eating, especially like some of the more primitive material we have could also be really good in the future (#13)'.

Taking advantage of this rich diversity is not always straight forward. The CPC maintains a mix of cultivated potatoes and their wild relatives. However, adaptation to Scottish growing conditions is not necessarily straight forward consequently varieties will be tested in the field and only those which can adapt will be kept and considered further for breeding purpose.

'Probably about 35-40% of the CPC is what we call primitive cultivated material, so this is material that will be eaten in the Andes for example. Stuff that's eaten as a crop you know or what we call like a land race (…) and so they do have good nutritional and culinary characteristics, they're things that have nice flavour quite often. But again, they're not great for growing in the field here' (#13).

A number of challenges are associated with the conservation of the CPC (or more largely with the conservation and use of genetic resources) among which is the cost associated with running the collection thus underpinning funding is essential to meet this cost. Indeed, the genetic material is conserved in gene banks that require specific laboratory equipment or in situ which involves their management in the field. Both types of conservation require time, energy, equipment and manpower. Additionally, in situ conservation involves some loss of diversity.

'The CPC is on a rotation, I think it takes about 50 years or so to get this whole CPC replanted [and] because it's true seeds, you don't want to maintain it too often, you lose diversity every time you cross things' (#03).

Beyond traditional breeding methods which appear to have limitations, new genetic engineering technics open opportunities to explore the agrobiodiversity but use of those techniques is currently limited

Traditional breeding techniques are expensive, take a long time for the selection of desired genes and the overall process is challenging particularly if the aim is to select a combination of genes. As a consequence, release of a new variety on the market is a costly process that can take up to 10 to 12 years.

'I think its…probably no more than 1% of all cross breeds actually end up being…less than 1% end up being given a name and having a market profile' (#12).

'We are trying to achieve the same [selecting a variety that gathers the quality of the Maris Piper] through breeding. The problem there is you will not get Maris Piper back. You will get something related to Maris Piper, but it will not have necessarily all the same qualities. That's just a fact of potato genetics. It is tetraploid, so you have 4 copies of every gene and because it's an outbreeder all these copies can be different. So, getting the right combination back is next to impossible (#03)'.

In addition, it is a constant race to breed in resistance before pathogens evolve, thus negating previous breeding efforts and leading farmers to eventually spray their crops.

'Potato is very susceptible to a lot of pathogens, probably more pathogen problems than other crops. And the pathogen is always evolving so you always have to kind of stay one jump ahead. Potato breeding is very slow, so it's actually quite difficult to stay one jump ahead, it's hard to get the resistance genes into the plants quickly enough before the pathogen evolves again. The sprays are quite toxic, a lot of sprays and soil treatments are used for potatoes, they're not very environmentally sustainable, they're quite toxic, some of them have residues and there are all kinds of issues with many of the chemicals used. So that's always important' (#13).

In an effort to overcome those limitations, modern genetics and genomics techniques such as gene editing and genetic modification are seen as increasing opportunities for exploring the genome of potatoes by reducing time and cost spent on breeding as well as allowing more precise gene selection and removing uncertainties.

'GM enables one to isolate the gene you are interested in (…). Otherwise, you're mixing 30,000 genes together and you're coming up with something that might be completely different. So, it's now it's resistant because it has the gene. But it's lost all the characteristics- possibly lost the characteristics. Or maybe even made them better' (#01).

'Modern genetics and genomics will play a big role in shortening this time. I mentioned earlier on the deployment of VNT1 it seems to be much faster than it would have normally happened (#03)'.

These technics used in combination with mapping the genome of potatoes are seen as promising for the future of potato breeding.

"The whole thing relies on knowing the gene, the gene in the first place, if you don't know the gene you don't know what you're looking for. So, cloning these genes has been a game changer. Now that we know we can look for over 30 resistance genes against nematodes, viruses and late blight. So now that we know what to look for now, we can make real progress with the breeding as well (#03)".

Nonetheless, the adoption of gene editing techniques is currently limited due to lack of capacity (labour) or government ban on genetically modified organisms. This is perceived as a drawback for the development of the sector to being better positioned on global markets.

'I mean you can use markers and things here and you can get to this point a lot quicker and go back and this is what's happening at the moment in a lot of places [abroad] but it's not happening…I don't think it's happening in the UK and you've also got to remember that potato breeding in the UK is mainly done here. There are not many companies doing breeding' (#13).

'The other big problem in Scotland is we are not allowed to use any kind of gene editing, or genetic modification technology. And I find that…extremely annoying. We need those technologies to breed potatoes with resistance to all the things vast teams of your colleagues are spending time trying to solve problems to and carry out research on. We need to be able to plan a Maris Piper that has gene resistance and has resistance to you know nematodes, to blight, to powdery scab, to everything. We need varieties that are easy to grow and the cost, the environmental cost is massive, I absolutely hate having to do it [spray pesticides] as a LEAF mark grower' (#14).

Despite interesting characteristics in new varieties, power structures and strategies implemented by stakeholders along the value chain as well as relative inertia on the market hamper their adoption and diffusion on the market

Current labelling practices of potatoes in the supermarket has led to undifferentiation of a range of varieties that potentially misleads consumers in their appreciation and use of potatoes. This has a detrimental effect on consumers' perception of potatoes whose knowledge of potato diversity is therefore limited.

'The biggest...the turnover, the churn, the big potatoes, the biggest shelf space is whites. (…) I think the problem with the decline of the fresh market is this term white [for white potatoes] … they'll be Saxon on Monday, they'll be Safari on Wednesday, they'll be Sapphire on Friday. And so the housewife will get one thing...the consumer buys like 5-6 Saxon, take them home, white potato, Saxon, they've got hard dry matter. You can bake them, you can crisp them, beautiful potatoes. Oh that was really nice, that was good, she'll go back, she'll pick up the same and they're Safari, it sounds like Saxon doesn't it? Takes them home, tasteless'! (#7)

At the same time, a smaller number of varieties are really appreciated by consumers for their sensory characteristics and are well established on the market as a consequence. As a consequence, new varieties with potentially interesting genes yet, such as disease resistant genes, fail to gain market shares and to get established as viable alternatives.

'There are some really exciting genes that have been cloned from wild species. And you do find them in cultivars. But they haven't penetrated the market yet and the reason for this one is people like their Maris Piper. Maris Piper is the number cultivar. The processors know how to deal with Maris Piper and if you like cooking…I never rated Maris Piper very much until I made some fries myself and they are stunning. They're really, really good' (#3).

Power structures within the sector that are characterized by the dominance of supermarkets and retailing companies restrains the range of new varieties that can enter the market and therefore innovation. As a consequence, some varieties are maintained that require a high number of

treatments on farms when research and breeding efforts and new techniques exist that could provide farmers with varieties that require much less inputs and treatments.

'Farmers need varieties that address the challenges of disease. In particular blight but also you know nematode resistant varieties and so on. But yet, year after year after year our customers tell us that they want Maris Piper, and this and that and the next thing. And they tell us that's what they require, and what I find really annoying is the lack of innovation by our customers [the retailers] with their customers, and the lack of innovation in variety development (…). And the lack of investment as well, the investment in James Hutton Limited today in new varieties by those customers is very very small and its falling' (#14).

Key actors' strategy along the supply chain are also reflected in the procurement of potatoes which is characterized by a reduction of the number of varieties. While this is considered to positively impact consumers' experience of potatoes, it has a negative impact on the introduction of new varieties to the market.

"One of our biggest challenges as a breeder is the fact that most of … and it doesn't matter whether it's table varieties, or processing, but most of the customers now have a much more restricted variety list than they did previously. I used to work for a company which packed for Y [supermarket] and a few years ago the Y approved variety list would have included some 150 varieties. Some were just niche heritage varieties, but there would be around about 150 varieties which they would accept. Now the target for W [packer] who now packs for Y is to get the approved variety list down to 30 varieties. And it's similar in processing, they want to use the same variety for a longer period of time than… and they want to avoid chopping and changing between different varieties. Which is good, it's…certainly…necessary for the consumer. So…um…it will give the consumer an improved experience definitely. But um…it makes it much more difficult to get new varieties into the packers, or the processors (#17).

Stakeholders' perceptions of the resilience of the potato sector

Respondents were given the definition of resilience as "the sectors ability to recover from shocks and bounce back to a state of equilibrium" then they were asked if they thought the potato sector was resilient. Opinions were diverse and sometimes contradictory as to what impacted on the resilience of the sector in a positive or negative way, but overall the sector was judged to be "fairly resilient". Factors identified as impacting positively or negatively the potato sector related to environmental factors, human capital, technological progress, market supply and demand, political factors related to the future relation of the United Kingdom with the rest of Europe and finally, structure of the supply chain and business models of the individual farms (cf. Figure 1).

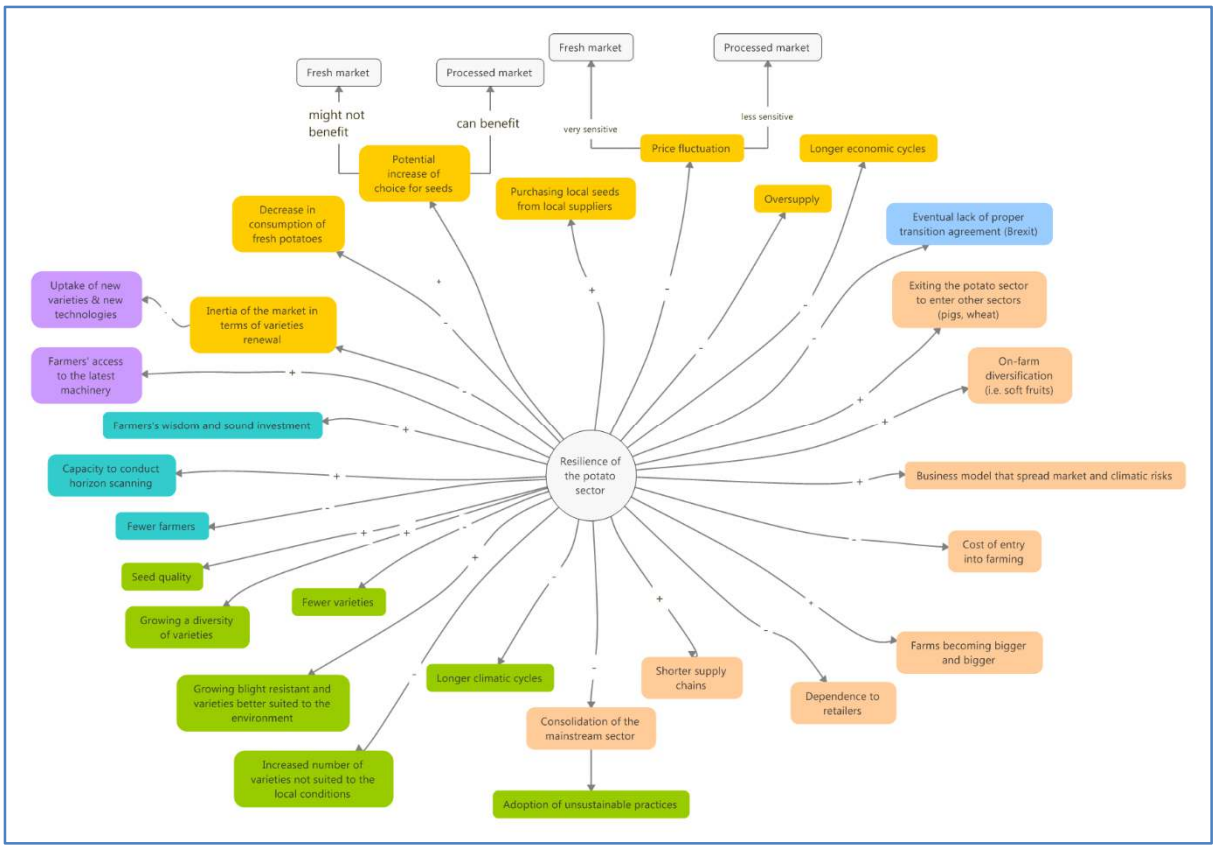

Figure 1 Factors affecting the resilience of the potato sector according to respondents (n = 18) (- represents a negative influence on the resilience of the sector while + represents a positive influence. Colour code for the different factors: green = environmental factors; turquoise = social capital; purple = technological progress; yellow = market demand and offer; beige = structure of the supply chain and business model of the individual farms; blue = political)

Environmental factors

Environmental factors related to the climatic conditions as well as to the plant material that is available and traded with the sector. The high quality of seeds produced by the Scottish seed sector was highlighted and considered an asset both from a production point of view (i.e. good quality seeds lead to good production in the ware sector) and also from a marketing point of view (since Scottish seeds are exported to Europe). An increased diversity of cultivated varieties was considered a factor of increased resilience while the opposite (i.e. the decrease in the diversity of varieties that are cultivated) was considered to have a negative impact on the resilience of the sector. Among diversity traits, blight resistance and traits that conferred on varieties the capacity to be productive under Scottish agro-pedoclimatic conditions were highlighted. Among factors cited as having a potentially negative impact on the resilience of the sector, was the decrease in the number of varieties that are grown. This loss in diversity was said to generate increased use of pesticides to maintain a good yield which was seen as being unsustainable.

Also believed to result in a negative environmental impact, is the consolidation of the industry, i.e farms becoming bigger and their reliance on heavy equipment for soil preparation and harvesting. Large businesses being tied to the market and therefore having fewer options as a consequence was identified as potentially leading them to adopt unsustainable practices with a negative impact on the environment. Finally, the seed sector was considered to have built in resilience in response to

economic and climatic cyclical variations but only providing difficult years do not last for too long: *"Maybe 2 years out of 3 are very bad (…) we are almost immune from variations in the market". Sometimes, you get 3 bad years and people (…) it got to a stage where people cut back severely. Now we are back on track but we loss more than 30% of our business over the course of years".*

Social capital

Factors that related to social capital referred to the existence of skilled farmers and breeders who have gathered expertise over years of farming and are technically efficient. Their capacity to conduct horizon scanning as well as to make smart business-related decisions and investments were seen as key features in adapting to changing conditions. The steady reduction in their number was perceived as having a negative impact on the sector over the long term. Increasing difficulties for businesses remaining in the sector may lead to stakeholders considering a range of strategies and different business models to enable increased resilience of the individual businesses.

Structure of the supply chain and business models of the individual farms

In this category, factors that impacted positively or negatively the potato sector related to the structural features of the farming sector and the potato supply chain in particular as well as to strategies and business models at the individual scale. Structural factors considered to have a negative impact on the resilience of the potato sector are the dependence on retailers and the power imbalances that occur in some cases, as well as the cost of entry into farming that reduces options for newcomers. Having to borrow money to purchase land can limit the amount of land that can be purchased and may make it more difficult for new entrants into farming to thrive from an economic point of view. In that context, the most resilient farmers were seen as being those that inherited land and who diversified into soft fruits 20 to 40 years ago. Among factors that were considered to positively impact the resilience of the sector were on-farm diversification (i.e. having another production along with potatoes), diversification into a different sector such as pigs or wheat and adopting a business model that enabled the farmer to spread risks, both economic and climatic. Farms that have the capacity to increase in business size were also seen as more resilient.

Market demand and offer

Factors considered to have a negative impact on the resilience of the sector were the decrease in the demand for fresh potatoes, price fluctuation, oversupply and longer difficult economic cycles (the succession of several bad years from an economic point of view). The fresh market was seen as more sensitive to price fluctuation than the processed market. Factors considered to have a positive impact on the resilience of the sector were contradictory. On one hand the potential increase of the choice of imported seeds was seen as bringing potential benefit to the processed market (more than to the fresh market) because of an increased choice in seed suppliers. On the other hand, purchasing seed from local suppliers was seen as positive, not only because of investment in the local economy but also because locally purchased seeds would be better suited to local conditions.

Technological progress

Technological progress was believed to have a positive impact on the sector. Farmers' access to and uptake of new machinery was considered to be important and of benefit to being competitive. Likewise, the availability of new breeding technics was seen as potentially having a positive impact on the sector but was also seen as constrained due to the relative inertia of supply and demand (i.e. the

same varieties dominating the market) and the subsequent difficulty in introducing new varieties to the market.

Political factors

Finally, Brexit negotiations were seen as having a potentially negative impact on the sector in the case of an "appropriate transition agreement" not being met. The argument was that the interests of the potato sector might not be well enough represented in future negotiations regarding trade agreements therefore failing to address the specificities of the sector (i.e. absence of subsidies).

Resilience of the potato sector: influence of a variety of factors

A systemic representation of the concept of resilience enables us to highlight the complexity of that concept, the interconnections between the different factors affecting the resilience of the sector and some apparent contradictions.

Resilience is a complex notion that relates to different categories of factors (environmental, technological, market supply and demand, political, structure of the farming sector) that are interconnected and have multiple interactions. Not only were opinions in some cases contradictory regarding the influence of a specific factor but also that different factors (in some cases, related) could have contradictory impacts on the resilience of the system overall. For example, the quality of the seeds produced in Scotland has a positive impact on the resilience of the sector but on the other hand, the introduction of imported seeds (i.e. seeds that have been selected in a different agro-pedoclimatic environment and then multiplied in Scotland) is considered to have a mitigated effect on the resilience of the sector. This is due to the fact that the discussion happens at a different level and other factors enter into consideration such as trade agreements, or globalisation of the seed industry that results in breeding objectives being determined by Dutch based enterprises with a branch in Scotland.

In addition, there is a tension between resilience at the scale of the individual business and at the scale of the sector. Indeed, at the individual level, a number of constraints push the individual business owner to make decisions aimed at improving the resilience of his/her own individual business (such as an exit strategy for example) but those same decisions might hamper the resilience of the whole sector. The number of farmers has drastically decreased since the 1970s to fall at about 2000 with the consequences it entails and therefore, threatening the productive basis over the long term.

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The views and recommendations expressed in this report are drawn from the participants and are not necessarily representative of the wider potato growing community. Furthermore, this report does not represent Scottish Government policy.

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