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Potato Breeding by Many Hands? Measuring the Germplasm Exchange Based on a Cultivated Potatoes Database

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ABSTRACT

In science, collaboration is sometimes understood as synonymous with co-authorship. However, it also can be measured through the exchange of information and materials. In agriculture, potato late blight is still a challenge to the breeding programs. Accessing different materials, which can be used as sources of resistance, is the key to successful disease control. This article maps the germplasm exchanges carried out by potato breeding in the world as a way to measure collaboration between countries. Cultivars of potato resistant to late blight were selected based on a European database and some countries stood out from others. This was mainly the case of Germany and the Netherlands. Most of the countries have greater links with themselves than with other countries, with reinforces the idea that national breeding programs work more closely within their own country than with other countries. The hegemony of some countries, the prioritization of national research and the high costs of developing a resistant cultivar can be obstacles to greater collaboration.

Keywords: Scientometrics; scientific cooperation; potato germplasm database; European Cultivated Potato Database.

1 Introduction

Potato is among the four most produced foods in the world (along with corn, wheat and rice) and it is the food with the most significant increase in per capita consumption in developing countries (Alexandratos and Bruinsma, 2012). Late blight, caused by *Phytophthora infestans*, is one of the most severe potato diseases. Consequently, it is not surprising that through genetic breeding, a considerable amount of effort and resource is directed towards the breeding of disease resistant plant cultivars. Thus, the exchange of germplasm between countries is essential to breeding programs, since having access to different materials is key to success in breeding. This exchange ensures international collaboration and avoids duplication of efforts in breeding programs, as well as optimizing the time to launch new cultivars (Baenziger and Depauw, 2009). Moreover, not all countries hold genetic diversity necessary to carry out their crosses and generate the desired cultivar.

We employ here cultivars database to measure collaboration on potato genetic breeding. The exchange of germplasm needed at crossings and held between the countries will serve as a measurement tool of collaboration in the development of cultivars resistant to late blight.

2 Why is collaboration important to the genetic improvement of potatoes?

Potatoes are an important staple crop for global food security. According to Alexandratos and Bruinsma (2012), the high dependence of developing countries on roots and tubers as a major source of calories should continue: six sub-Saharan African countries will still rely on potatoes for more than 30% of total food consumption (calories) in 2050. Thus, the per capita consumption of potatoes will continue to grow.

Productive gains in potatoes can come directly from increasing productivity or reducing losses with the use of disease resistant cultivars, for example (Joshi et al., 2010). In potato, since it has caused Irish hunger, the *Phytophthora infestans* oomycete remains the largest enemy of potato crop worldwide (Fisher et al., 2012). According to OECD / FAO (2012) data, the annual amount that is lost globally due to pathogens is estimated at 39 billion dollars. Consequently, it is not surprising that through genetic breeding, a considerable amount of effort and resource is directed towards the breeding of disease resistant plant cultivars. With these resistances, there is also a lower need for pesticide use. In potato, annual losses and fungicide costs in developing countries have been estimated at over 10 billion euros (Haverkort et al., 2009). In this case, therefore, genetic improvement seems to be the most effective tool to increase agricultural efficiency and feed the world in a sustainable way (Bennett and Jennings, 2013).

Genetic plant breeding is a continuous process, in which the development of a commercial cultivar can take many years to complete (Forbes, 2012). The aggregation of a single characteristic to a cultivar, such as resistance to a specific disease, involves a complex, time-consuming and expensive process of genetic improvement. For example, varieties that are completely resistant to disease and adapted to different growing environments are still needed. Likewise, the conservation of its characteristics over time requires the application of rigorous control processes of purity and quality of this material.

Thus, the exchange of germplasm between countries is essential to breeding programs, since having access to different materials is key to success in breeding. We present below the methodological procedures used to measure collaboration from potato cultivar database.

3 Method

This work is based on data analysis obtained from a bank of potato cultivars, The European Cultivated Potato Database (ECPD) (https://www.europotato.org/menu.php). It is an online database maintained by eight European Union countries and five Eastern European countries. The European Cultivated Potato Database currently has information on more than 4,136 cultivated varieties (Bradshaw, 2010). As it gathers characteristics of cultivated potatoes from studies conducted by many research institutes across Europe, several authors have used information from this database. Hansen et al. (2005), for example, used its information to evaluate Phytophthora infestans foliar resistance in potato. Bianchi et al. (2014) used information about cultivars retrieved from the database to analyze storage ability and dormancy period of seventeen potato varieties. Esnault et al. (2016), Schönhals et al. (2016), Porter et al. (2017), Śliwka et al. (2017), among others, are some of the authors who also used information from The European Cultivated Potato Database in their works.

In the world, 90% of potato production occurs in the northern hemisphere. Europe is the largest consumer of the tuber in the world and the second largest producer, only behind Asia.

In the database, cultivars with foliar resistance (*Phytophtora infestans*) were selected: a) medium to high resistance, b) high resistance, c) high to very high resistance, d) very high resistance. Foliar resistance was chosen because fungicide application and foliar resistance are expected to decrease the amount of inoculum to which the tubers are exposed to and thus to minimize the risk of late blight also in the tuber (Naerstad et al., 2007). A total of 1470 cultivars from the European database were used. Information about the cultivar's country of origin, the parent cultivars' countries of origin and the cultivar's holder were also collected.

The database selection has met some requirements such as: being available online; make the criteria selection possible, such as resistance to disease; and provide information about the cultivar's name, the country of origin, its parents and the parents' countries of origin.

From this information, collaborative relationships were established between the cultivars' countries of origin and their parents' countries of origin. For each link between the cultivar and one of its parents a line of collaboration was counted. In order to facilitate the construction of maps of collaboration between countries, in this paper, we consider only those cultivars with two parents. In the case of potatoes and the databases used, most of the cultivars were derived from only two parents. In other cases, however, the use of two parents is not sufficient to provide the cultivar with the necessary combination of characteristics. This is what happens, for example, with wheat and rice cultivars. They can have up to ten parents, making it difficult to trace the source countries. Moreover, it is important to note that, globally, potato breeding is still mostly carried out by public or private institutions of medium size, which facilitates access to information about the crossings (Douches et al., 2014). When the breeding is carried predominantly by large private companies, information on the parents used and carried crosses are not disclosed. This is the case concerning corn, for example, where the most productive and used hybrids are under the control of large private companies (Pray and Fuglie, 2015).

Therefore, the choice of potato as the object of study of this work occurred for the following reasons: 1) it is among the four most important foods in the world; 2) its main pathogen has as its most important control the genetic improvement of the cultivars; 3) it generally requires only two parents for the development of a new cultivar; 4) there is information available on parents and crossbreeding.

Data were collected from April to August 2016. International collaboration maps, charts and calculation procedures were performed using Excel, Tableau 10.1 and RTBMaps software version 1.0.

In terms of quantity indicators, this study applied to the Salton's measure for normalization of data (Glänzel et al., 2009; Ali-Khan et al., 2013). It is considered an indicator of the strength of mutual collaboration between two countries. This study changed the subjects from papers to cultivars, investigating which of the countries have relatively strong collaborative relationships. The higher the indicator is, the stronger the relationship between the two countries. The values do not indicate the amount of cultivars developed by the countries, nor show their prominence in the network. Thus, bilateral collaboration strength S_{ik} can be measured by the following formula:

$$S_{ik} = \frac{n_{ik}}{\sqrt{n_i \times n_k}}$$

Where n_i is the number of total cultivars of country *i*, n_k is the total number of cultivars of country *k, and* n_{ik} is the number of links between both countries.

4 Results

In database, 1470 cultivars with resistance to late blight were found. Of these, 30% are German and 26.2% are Dutch. This demonstrates the dominance of cultivars resistant to late blight of these two countries in comparison to the others. This fact can be explained mainly by two reasons: a) the great food industry and economic importance of potatoes for Germany and the Netherlands and b) the increasing demand of consumers and local legislation for a decrease in agrochemicals use in the crop (European Parliament, 2009; Jess et al., 2014).

Germany is currently the seventh largest potato producer in the world and the largest in Western Europe with a production of 11.6 million tons (FAOSTAT, 2014). This corresponds to 20% of what is planted throughout the European Union. In addition, almost 60% of potatoes produced by Germany are used for human consumption, which is why it is also an important processor and exporter of potatoes. Figure 1 shows the geographical distribution of potato cultivation worldwide. Asia and Western Europe stand out as the regions with the largest potato production in the world.

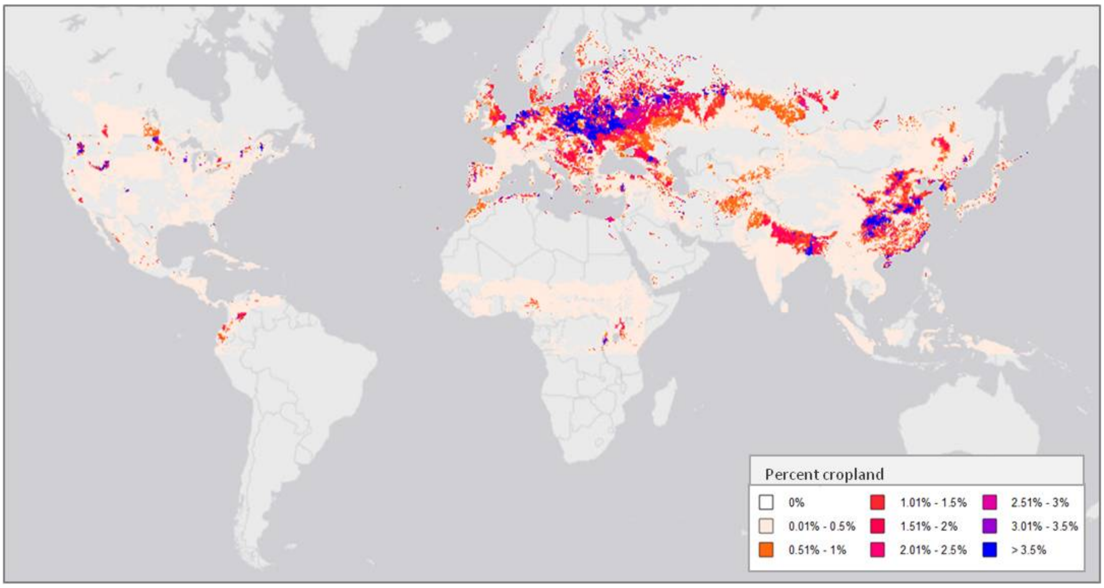

Figure 1. Geographic distribution of potato cultivation in the world. Source: FAOSTAT (2014).

In addition to being consumed directly, potatoes are transformed into four main types of products: frozen potatoes, dried potatoes, potatoes prepared or preserved and potato starch. In 2014, Germany processed the equivalent of 65.9% of all European Union dry potatoes and exported 1.3 million tons of fresh potatoes and 2 million tons of processed products (FAOSTAT, 2014).

Likewise, the Netherlands grows almost 25% of its arable land - about 160,000 hectares - with potatoes and has reached the world record with average productivity of more than 45 tons per hectare. Half of the potatoes grown in the Netherlands are for human consumption - about 20% are from seed potatoes and the remaining 30% are processed into starch. In addition, the Netherlands is the world's leading supplier of certified seed potatoes, with exports of about 700,000 tons per year (FAO, 2008; FAOSTAT, 2014). For a global perspective on the international trade of seed potatoes, Figure 2 shows the trade links between 2006 and 2009. The map was constructed by Kleinwechter and Suarez (2012) and to avoid overloading the map, the authors considered each link between the countries with an average value of imports or exports of 100,000 US$.

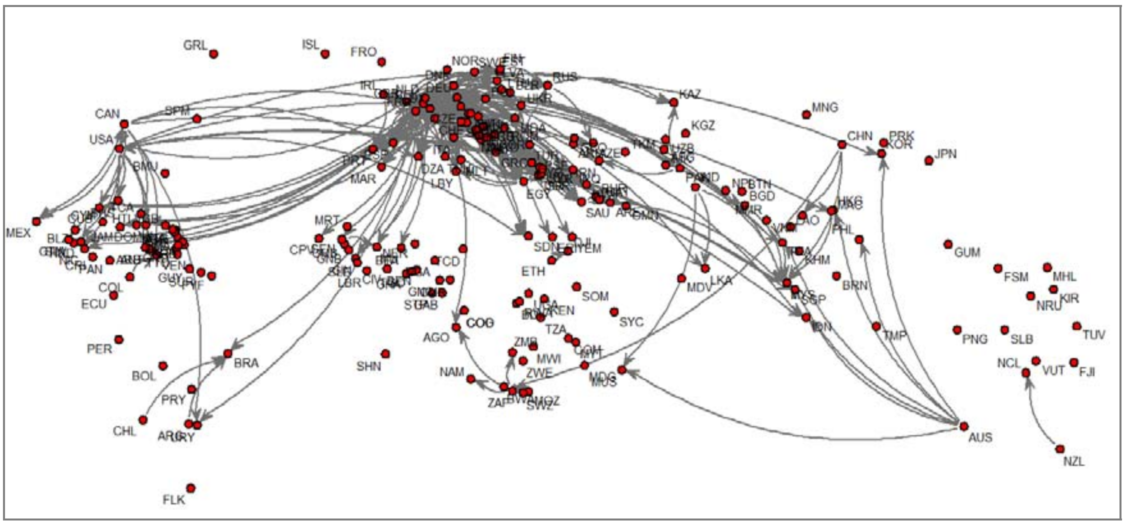

Figure2. Trade links of seed potatoes in the world between 2005- 2009. Source: Kleinwechter and Suarez (2012).

The map brings some interesting insights into the structure of the global seed potato trade. Although there are trade connections spanning the globe, there are regional concentrations. There is a strong concentration of trade links in Europe and between Europe, North Africa and Asia. The United States and Canada, in addition to negotiating with each other, are the main exporters to Central America and the Caribbean. In South America, Argentina and Chile seem to have a central position in the export of seed potatoes, while Brazil appears as a major importer of these two countries. In the Oceania region, Australia and New Zealand appear as exporters to the countries of Southeast Asia and the Pacific Islands. In Africa, South Africa is a central supplier of seed potatoes. In the same way (but less visible on the map), the countries of North Africa and Asia import seed potatoes from Europe. The countries of Europe dominate the international trade in seed potatoes as raw material exporters.

At the same time, one third of the European Union's total area of organic potatoes is in Germany (followed by Austria (12.9%), France (8.9%), Poland (8.5%) and the Netherlands (6.2%)) (Eurostat, 2013). The organic cultivation of potatoes, as well as the reduction of the use of agrochemicals in conventional crops is only possible with the use of cultivars that present some degree of resistance to the main diseases, such as the late blight. Many studies have shown that resistance to late blight can save on fungicides, reducing the number of applications of the product or increasing the intervals between applications throughout the crop cycle (Bradshaw and Bain, 2007; Bain et al., 2008; Cooke et al., 2011). In spite of these advantages, important commercial characteristics such as quality, precocity and productivity are not usually combined with resistance to late blight in the same potato cultivar. Therefore, in Western Europe resistant cultivars are not cultivated on a large scale by farmers (Cooke et al., 2011). However, in countries where fungicides are not available, are too expensive or prohibited by legislation, as in the case of organic food production, the use of resistant cultivars becomes the most important resource to control late blight.

Between 2000 and 2007, 20% of organic potato producers in the Netherlands stopped producing potatoes because there were no late blight resistant cultivars and no alternative fungicide for the disease is allowed in the country (Lammerts van Bueren et al., 2009). Similarly, the council regulating the use of pesticides in Europe in 2009, during a review in its legislation, took away many fungicides from the market, including some used for potato late blight control (Cooke et al., 2011). Consequently, the United Kingdom, Poland, Russia and France stood out for having a large number of resistant cultivars according to the analyzed database. The availability of disease-free cultivars has been a key issue for these countries against the limitations of fungicide use.

Table 1 details the occurrence of cultivars by country of origin and levels of resistance to late blight. It is observed that 54.6% of all potato cultivars registered as "resistant to late blight" in the databases have medium to high resistance, while 39,3% have high resistance. Germany and the Netherlands have mainly potato cultivars with medium to high and high resistance to late blight. Of the 60 cultivars with high to very high resistance to late blight, the Netherlands owns 53% of them. Only 30 cultivars registered in the databases have very high resistance to late blight and 12 of them belong to Germany. Poland and the United States stand out because they have four very resistant cultivars each.

Table 1.
Total occurrence of cultivars found in the database analyzed, detailed by country of origin and levels of foliar resistance to late blight.

Country of origin	Total occurrence of cultivars	Level of resistance			
		Medium to high	High	High to very high	Very high
Australia	**2**	-	2	-	-
Austria	**34**	26	6	2	-
Belgium	**12**	-	12	-	-
Brazil	**2**	2		-	-
Belarus	**18**	8	10	-	-
Canada	**12**	2	10	-	-
Czech Republic	**48**	28	20	-	-
Denmark	**28**	10	14	4	-
Estonia	**14**	6	8	-	-
Finland	**8**	2	6	-	-
France	**66**	42	22	-	2
Germany	**444**	250	176	6	12
Hungary	**22**	6	14	2	-
Ireland	**14**	6	6	2	-
Japan	**2**	-	-	-	2
Latvia	**2**	-	2	-	-
Mexico	**2**	-	2	-	-
Netherlands	**388**	242	112	32	2
New Zealand	**2**	-	2	-	-
Norway	**4**	2	2	-	-
Poland	**70**	42	24	-	4
Romania	**10**	2	8	-	-
Russia	**68**	36	28	2	2
Serbia	**16**	12	4	-	-
Slovenia	**4**	4	-	-	-
Spain	**10**	-	10	-	-
Sweden	**10**	2	6	2	-
Ukraine	**10**	-	10	-	-
United Kingdom	**106**	54	42	8	2
United States	**42**	18	20	-	4
Σ	**1470**	**802**	**578**	**60**	**30**
%	**100%**	**54,6%**	**39,3%**	**4,1%**	**2%**

More than half of the resistant cultivars of the database have medium to high resistance to late blight. As previously mentioned, the agronomic characteristics of the cultivars with high or very high resistance may justify the reduced presence of these cultivars in the databases. The potato market favors many qualities, and a cultivar that has either little or no resistance to disease can be selected for other attributes such as tuber size and more uniform shape. Market demand has been recognized as a factor that influences and often limits the volume of development and consequently the use of cultivars by farmers (Forbes, 2012). This effect is stronger in the industrialized world, where market components have become highly specialized (Walker et al., 1999).

In order to meet this market, industrialized countries present many small and medium-sized potato breeding companies and highly developed seed industries that can rapidly multiply and distribute new cultivars (Hoekstra et al., 2001; Forbes, 2012). Of the 1470 resistant cultivars recorded in database, 500 provide information on who are the cultivar breeders. It is believed that the limited number of breeders in the European database is due to the fact that many potato cultivars are selected and developed by the farmers themselves. In the Netherlands, for example, in 2009, 293 potato cultivars were developed. Half of these cultivars were selected by breeders farmers, reaching 44% of all planted area with seed potatoes of the country (Almekinders et al., 2014). Table 2 shows the top ten breeders with the most cultivars in the databases. Germany and the Netherlands stand out against the other countries as the ones that develop more resistant cultivars to late blight. Germany holds the top three database breeders, followed by the Netherlands.

Table 2.
Ten major breeders found in the database analyzed and the number of cultivars recorded by each.

Breeder	Number of cultivars
Asche-Saatzucht	59
Biologische Reichs	17
Franz von Zwehl Saatzucht	13
Cebeco Handelsraad B.V. (Cefetra®)	10
Nordkartoffel Zuchtgesellschaft (Europlant®)	9
Kartoffelzucht Böhm (Europlant®)	8
Uniplanta-Saatzucht KG (Solana®)	8
C. Raddatz-Hufenberg	7
Nicolas Frh. von Pfetten-Arnbach	7
Nordostbayerischer Saatbauverband	7

The first breeder company on the list, Germany's Asche-Saatzucht, is responsible for 11% of the blight-resistant cultivars registered in ECPD. The following three respond together for 7.9% of the resistant cultivars. Biologische Reichs and Franz von Zwehl Saatzucht are also companies from Germany, and Cebeco Handelsraad B.V. (now Cefetra®) is Dutch.

In Germany, in general, plant breeding and seed marketing are well organized activities of a specialized sector of the agricultural economy and comprise mainly the development of modern cultivars. Around the world, there is no other place with so many breeding activities carried out independently by private plant breeding companies. There are about 100 private companies, medium-sized, that work on the development of cultivars. Competition among these companies is complemented by cooperation, as many breeders share a seed marketing cooperative (FAO, 2009). Since 2002, the technological know-how and improved cultivars of Kartoffelzucht Böhm and Nordkartoffel Zuchtgesellschaft have been incorporated into the Europlant® brand, which operates with three breeding stations and four test stations in Germany, the Netherlands and France. The breeding work developed in the company is oriented towards the introduction of resistance and quality characteristics of the wild potato species in the cultivated potatoes (Pandey et al., 2010).

When analyzing the main cultivars used as progenitors of resistant cultivars, Germany, United States and the Netherlands remain ahead of the other countries. Table 3 shows the top 20 progenitors used in the greatest number of crosses and their countries of origin.

Table 3.
Twenty main cultivars used as progenitors in the crosses, number of crosses in which each one is used and their respective countries of origin.

Main progenitors	Number of crosses	Country of origin
Aquila	22	Germany
Katahdin	18	United States
Hindenburg	11	Germany
Flava	10	Germany
Schwalbe	10	Germany
SVP AM 66 42	10	Netherlands
Desiree	9	Netherlands
Olev	9	Belarus
Clivia	8	Germany
MPI 19268	8	Germany
Capella	7	Germany
Cara	7	Ireland
Libertas	7	Netherlands
Maris Piper	7	United Kingdom
Maritta	7	Germany
Merkur	7	Germany
Record	7	Netherlands
USDA X96 56	7	United States
Jubel	6	Germany
Provita	6	Netherlands

The German cultivar Aquila, which is mostly used in the crosses (2% of them), is product of the improvement for resistance to late blight. It is an old cultivar which is said to be the main responsible for introducing resistance in several crosses around the world (Davidson, 1980). It originates from a potato species *(Solanum tuberosum*) that has the R1 gene of *S. demissum* (a wild species). Much of the resistance to late blight present in the potatoes is originated from *S. demissum*. However, this gene may lose its effectiveness as new and more aggressive races of *P. infestans* appear which can overcome resistance (also called specific resistance). For example, isolates of *P. infestans* that outweigh all 11 R genes have already been identified. In contrast, another type of resistance, the non-specific one (which is usually controlled by several genes), could potentially be more durable. Recently, many potato breeding programs have been attempting to identify and map these genes for inclusion in new cultivars.

The North American cultivar Katahdin, second on the list, has many flowers and fertile pollen, being therefore widely used as a parent in breeding programs and appears in the pedigree of many cultivars of the northern hemisphere (De Jong et al., 2011). The third one on the list, the German cultivar Hindenburg, is used in breeding programs because it is resistant to common scabies, another important potato disease (Sedláková et al., 2013).

It is important to note that the three potato cultivars most used as progenitors represent just over 6.3% of the crosses, while the 20 on the list represent 22.8% of them. In addition, these 20 belong to only six different countries: Germany, the Netherlands, Belarus, Ireland, the United Kingdom and the United States. Together these six countries hold nearly a quarter of the most used crossbreeding parents. Thinking in terms of genetic diversity, there is little use of parents from other countries. Basically, the countries that have the majority of the cultivars resistant to late blight also have their main progenitors. Some of these genetic materials, however, have come from South American countries.

Peru is considered the center of origin of potato and Mexico of *Phytopthora infestans*. They would have genetic diversity to be used in crosses that aim for resistance to late blight (Goss et al., 2014). For this reason, both Germany and the Netherlands have made numerous expeditions to these sites in search of materials for their breeding programs. A number of authors report these expeditions, which occurred in different periods, such as the Dutch expedition to Peru (Toxopeus, 1956), the German expedition to the Andes (Ross, 1960), the Dutch-English expedition to the Andes in 1974, and expeditions to Bolivia (van Soest et al., 1983; Spooner et al., 1994), Guatemala (Spooner et al., 1998) and Costa Rica.

Many of these germplasm exchanges are not documented. This is because in South America, especially in Peru, the law authorizing the export of vegetable materials was only implemented in 1992 by the Peruvian government (Hoekstra et al., 2001). Thus, there is also no record on which cultivars were brought to Europe in each expedition. These exchanges could be characterized as informal collaborations between countries, since there were no formal agreements for most of these expeditions. This germplasm originally introduced in Europe had late flowering and tuberization. By selection, this introduction was adapted to tubing under conditions of longer day length and different environmental conditions in Europe. Simmonds (1996) has shown that this transition can occur within 10 years, relatively short for breeding. From Europe, this new type of potato has spread all over the world as the cultivated type of this vegetable. In order to understand the formal collaborations established between countries, the following map shows the main germplasm exchanges recorded in the databases analyzed.

Figure 3 shows a map of collaboration between the countries of the cultivars and their parents. All levels of collaboration are represented in it. Thus, seven types (or thicknesses) of lines were used to represent the disparity of links, with thicker lines indicating higher levels of collaboration. The numbers in each row reflect the number of links between each country. In addition, two colors were used to differentiate the countries that are holders of late blight resistant cultivars (blue) from those that provide progenitors for crosses (orange). In some cases, the same country can provide parents and be holder of cultivars.

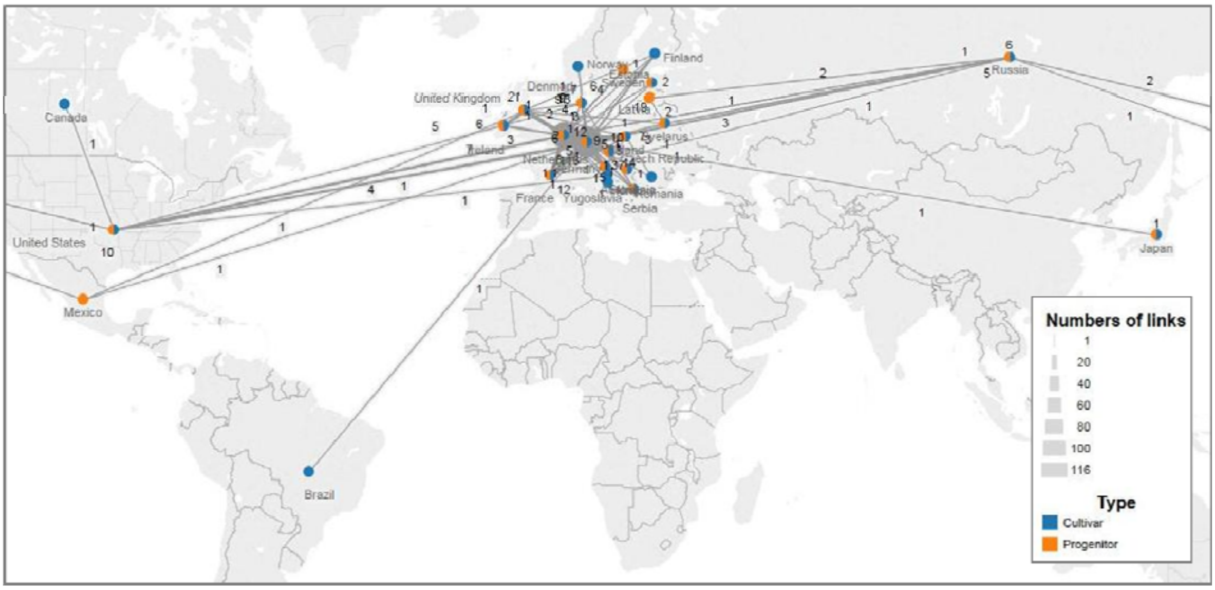

Figure3. Map of collaboration between the countries of the cultivars and their parents according to the database analyzed.

Comparing this graph with that of the global trade of seed potatoes, it becomes apparent that links in both graphs have similar geographic structure. Although there are connections covering the whole globe, in both networks a tendency can be observed for the concentration of connections, especially in Europe. This intense network of links between the countries of Europe will be detailed below. In addition, many lines link these countries to countries outside Europe. The main one is the one which connects the Netherlands with the United States. These two countries are important holders of cultivars and also parents owners, as discussed above. There are seven links between these two countries, the greatest collaboration between a European country and a non-European. It is also worth mentioning the line between Germany and Russia, with five links.

Among countries outside Europe, the largest collaborations involve the United States and Russia, with 10 and 6 connections respectively. What is striking, however, is that these collaborations occur within the same country, that is, each country provides parents for their own potato cultivars.

It is also noted that Mexico, as the possible center of origin of *P. infestans,* only provides parents to other countries. When analyzing the data standardized by Salton's measure (Table 4), it is observed that most countries' connections are relatively weak, and strong international collaboration relationships (Salton's measure> 0.05) are seen only in a small proportion between countries. Salton's measure converts the values (observed) into values that relativize the intensity of collaboration of two countries, in relation to the quantity of cultivars of each country individually. Therefore, according to the table, the link between Ireland and the United Kingdom is the strongest, followed by links between Russia and Latvia, Latvia and Byelarus, France and the Netherlands, and Serbia and the Czech Republic. This means that in this case, the geographic proximity of countries can have an effect on the collaborative relationships of cultivar changes. This means that, in proportion to the number of cultivars of each country, these are the strongest collaborations. It should also be noted that, in the table, when comparing the links of all countries, Germany and the Netherlands have strong links with at least four other countries each.

In Figure 4, the links among the countries of Europe are detailed. Germany and the Netherlands are the two countries with the highest number of connections. In isolation, Germany has 116 connections and the Netherlands 97. Among them, there are 37 connections. With France and the Czech Republic, Germany has 19 and 12 connections, respectively. The Netherlands has 14 connections with the UK and 13 with France. The latter two, in isolation, have 21 connections (UK) and 12 connections (France).

In general, the countries that most collaborate are Germany and the Netherlands, due to the number of connections between them. However, it is also important to consider the number of collaborations only within the country. Germany is an example of a country that provides parents for the development of their own cultivars, that is, it collaborates more with their own crosses than with other countries. 57.7% of the 201 German connections occur to itself. This means that it has developed resistant cultivars from its own parents and collaborated little with sending or acquiring parents from other countries. The same happens with the Netherlands: 51.8% of the 187 country's connections are registered with itself. The great collaboration between Germany and the Netherlands can be explained by the cooperation agreements that the two countries have held together since 1974 (Lange, 1976). In 1984, one of these cooperation agreements made it possible for other institutions in Europe to participate, and in 1995 the collection of materials resulting from this partnership was transferred to the Netherlands Genetic Resources Center in Wageningen. Approximately 26% of this collection originates from previously explicit expeditions, carried out in partnership between the two countries (Hoekstra et al., 2001).

Another fact that draws attention to the map is that both Sweden and Latvia only provide parents. On the other hand, Finland, Norway, Romania and Slovenia have potato cultivars that are resistant to late blight but do not provide parents. As such, they only purchase cultivars from other countries without providing their genetic material.

Despite having links with other countries on the map, all of these countries collaborate little internationally, since the route is only one way, that is, either only providing or acquiring the genetic material. There is no exchange, a fundamental concept of collaboration.

Table 4.
Salton's measure for bilateral collaboration amongst the countries, highlighting five links with the strongest relationships.

Salton's measure for billateral collaboration amongst the countries																	
	Den-mark	France	Germany	Hunga-ry	Japan	Latvia	Mexico	Nether-lands	Nor-way	Poland	Romania	Russia	Serbia	Slovenia	Swe-den	UK	USA
Austria	-	-	0,073	-				0,052	-	0,02	-	-	-	-	-	-	-
Brazil	-	-	0,033	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Belarus	-	-	0,033	-	-	0,166*	-	-	-	-	-	0,085	-	-	-	0,022	-
Canada	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,044
C. Republic	0,027	-	0,082	-	-	-	-	0,021	-	-	-	-	0,108*	0,072	-	-	-
Denmark	--	-	0,062	-	-	-	-	0,019	-	-	-	-	-	-	-	0,018	0,029
Estonia	-	-	0,012	-	-	-	-	0,013	-	-	-	-	-	-	-	-	-
Finland	-	0,043	0,083	-	-	-	-	0,018	-	-	-	-	-	-	-	0,034	-
France	-	-	0,07	-	-	-	-	0,112*	-	0,014	-	0,015	-	-	-	0,012	-
Germany	-	-	-	0,01	0,033	-	0,033	0,09	0,071	0,045	0,015	0,028	0,047	0,023	-	-	0,029
Ireland	-	-	-	-	-	-	-	0,067	-	-	-	-	-	-	-	0,233*	-
Latvia	-	-	-	-	-	-	-	-	-	-	-	0,171*	-	-	-	-	-
Mexico	-	-	-	-	-	-	-	-	-	-	-	0,085	-	-	-	0,06	-
Netherlands	-	-	-	-	-	-	-	-	-	0,036	-	0,006	0,025	0,025	0,032	0,07	0,054
Poland	-	-	-	-	-	-	-	-	-	-	0,037	-	-	-	-	0,023	0,018
Russia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,037
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0,077

* Five links with the strongest international collaboration relationships (Salton's measure> 0.05) among the countries analyzed.

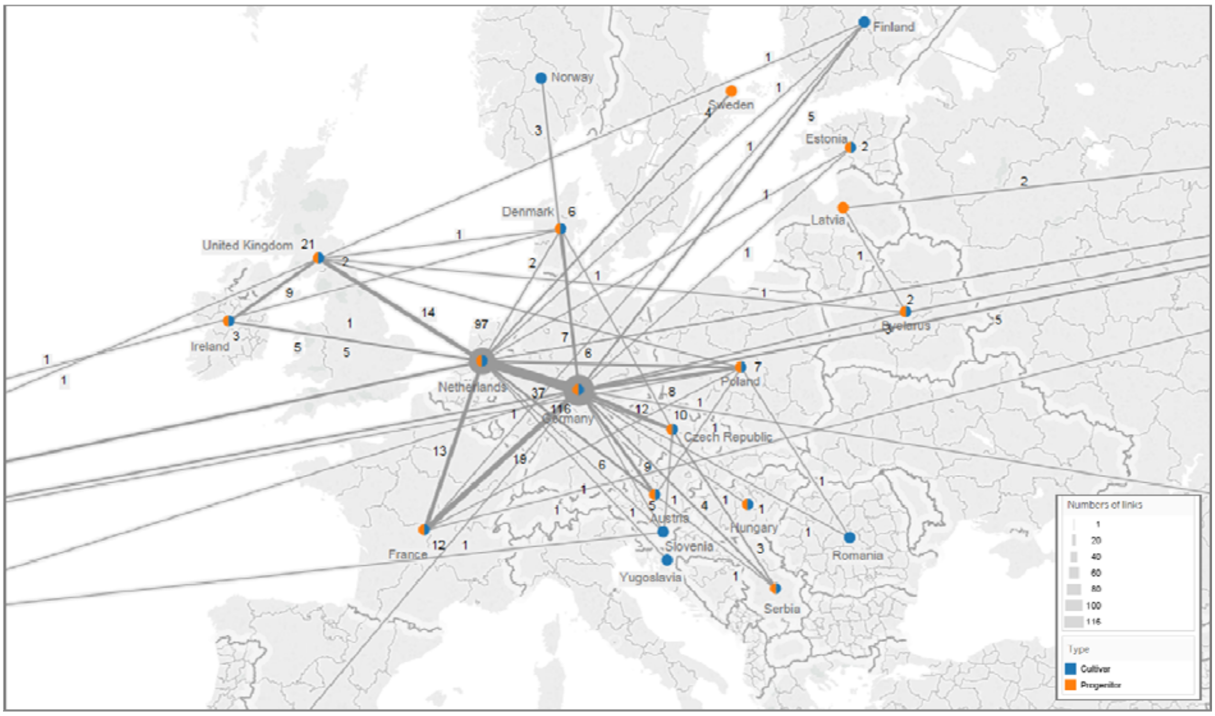

Figure 4. Collaboration map between the countries of the cultivars and their parents, highlighting the countries of Europe, according to the database analyzed.

5 Final Discussions

Graphing the exchange relationships of potato germplasm provides interesting information on the development of resistant cultivars and how the distribution of these cultivars may interfere with the management of late blight disease worldwide. But what about the initial question of measuring collaboration between countries and also the implications of these relationships for potato breeding?

Firstly, there are a large number of links between countries, although these links mainly cover European countries. This reiterates the importance of potatoes to the European continent, which was until the 1990s the largest producer and consumer of potatoes in the world (later surpassed by Asia). Especially the Netherlands and Germany have a significant role in both the production and development of cultivars and the export of potatoes to the rest of the world. However, the bilateral collaboration established between these two countries puts them ahead of the others in the number of cultivars resistant to late blight, in the number of breeding enterprises and in the number of parents. It is a beneficial agreement for the two countries, which have already carried out expeditions to collect plant materials from the Andes, in search of greater genetic diversity for their cultivars. However, little collaboration with other countries limits the likelihood of selection of cultivars that fully meet agronomic and commercial needs, such as disease resistance and tuber quality. Another important aspect is that India and China are currently the world's largest producers of potatoes, but they do not even appear on the map of resistant cultivars (FAOSTAT, 2014).

In addition, an important objective of any breeding program is to shorten the time needed to make new cultivars available to farmers. Since the potato has a very low multiplication rate, producing seeds of a new cultivar requires several seasons. With expanded collaboration to other countries, the development of new cultivars may occur more rapidly. Moreover, collaboration is especially relevant in promoting the transfer of knowledge. This knowledge may be related to the capabilities needed to more effectively identify new potato cultivars (such as those resistant to late blight) or only to disseminate research results. Thus, for example, information on the performance of cultivars in one country may guide the selection of candidate cultivars in other countries.

Nevertheless it is important to note that the cost of developing a resistant cultivar is not low. Breeding programs need time and investment. Germany stands out because it has medium-sized private companies that together collaborate in the development of new potato cultivars. But this is not the case in most other countries, especially developing ones, where breeding programs rely on public resources and deadlines determined to deliver results. It is no wonder that China, one of the most capitalized countries in Asia, has outpaced European countries in potato production in recent years as the Chinese government has invested heavily in agricultural research and development in the country.

In countries where investments in this area are not so voluminous, collaboration with other countries takes place through the importation of already developed resistant cultivars. Some countries in Africa and Asia that do not appear on the map, for example, have developed partnerships with the Netherlands and Peru for development and acquisition of cultivars that are resistant to late blight and adapted to their growing regions. For example, cultivars of the International Potato Center (CIP) in Peru had a significant impact on the poorest countries of sub-Saharan Africa in 2007. In seven of the eight countries sampled in a survey that year, CIP cultivars occupied the largest proportion of total planted area, with 92,000 hectares in Rwanda, 30,200 hectares in Uganda and 67,000 hectares in Kenya. In Burundi and the Democratic Republic of Congo, CIP varieties occupy almost all potato planted area (CIP, 2016). China and the Netherlands also work in a partnership to buy seed potatoes, the Orange Potato project. One of objectives of the project is the sharing of Dutch knowledge and technology in the storage and processing of potatoes. There is also cooperation between Chinese and Dutch agricultural universities, organization of fairs to farmers and trade missions of Dutch delegations to China and Chinese authorities and companies to the Netherlands (NAFTC, 2013).

Although these examples of international collaboration are not in the database and therefore in the maps presented (because they do not represent germplasm exchanges between countries), they reiterate the importance of sharing information, knowledge and genetic material in the fight against potato late blight. Because a European database was analyzed, some countries stood out from the others. This was mainly the case of Germany and the Netherlands.

The fact that most of the countries on the map have greater links with themselves than with other countries reinforces the idea that national breeding programs work more closely within their own country than with other countries. In genetic breeding the exchange of germplasm is the first step and the development of a resistant cultivar is consequently followed by the multiplication of seed potatoes and the diffusion to farmers. In this work we aimed to measure collaboration only in the first step, but we know that it is also fundamental in the following steps. We know that the links presented here do not represent all the collaborations between the countries, but they can serve as indicative of how the genetic breeding of the potato, especially the exchange of germplasm, has been faced by the different countries and can help the management of late blight in the future. In addition, the availability of databases with complete information on the origin of cultivars and parents, for example, could relevantly contribute to a greater understanding of international collaboration. The same could be done concerning the collaborations for the distribution of the newly developed cultivars and for the acquisition of seed potatoes.

Conflict of Interest

The authors declare that they have no conflict of interest.

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