FEDERAL UNIVERSITY OF RIO GRANDE DO SUL

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GRADUATE PROGRAM IN AGRIBUSINESS

LILIAN CERVO CABRERA

COOPERATION IN SCIENCE: THE ROLE OF SCIENTIFIC COLLABORATION IN THE STUDY OF DISEASES IN WHEAT AND POTATO CROPS

Porto Alegre

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Co-advisor: Prof. Dr. Homero Dewes

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Agribusiness Doctoral Thesis
Federal University of Rio Grande do Sul

COOPERATION IN SCIENCE: THE ROLE OF SCIENTIFIC COLLABORATION IN THE STUDY OF DISEASES IN WHEAT AND POTATO CROPS

Author: Lilian Cervo Cabrera
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ABSTRACT

Plant diseases can cause heavy losses and pose a real risk to global food security. To meet this challenge, cooperation among agribusiness stakeholders is fundamental. Thus, this thesis aims to measure and analyze the role of cooperation - scientific collaboration - in the management of diseases in plants, specially wheat and potato. Therefore, three studies are presented on this theme. The first study aims to characterize and study the functioning of some agricultural research networks that monitor pathogens, develop and distribute disease resistant cultivars, and sequence wheat and potato genomes. In it, it is also discussed how some pathogens may threaten the stability of wheat and potato production in the world, especially the fungus *Puccinia graminis* f. sp. *tritici*, that causes stem rust in wheat, and the oomycete *Phytophthora infestans*, that causes late blight in potato. Different institutions, such as consortia, research centers and established institutions are considered to illustrate their involvement in networks and to discuss their activities. The second article seeks to measure scientific collaboration in publications available in Web of Science through co-authorship analysis. The objective was to map countries that collaborate scientifically in the area of food security. We considered articles published in the period from 1996 to 2016 and the results were analyzed using VOSviewer software. The third article seeks to map the germplasm exchanges conducted by potato breeding programs in the world to measure collaboration between countries. In this article, information was only used on the potato. Cultivars of potato resistant to late blight were selected based on two databases, a European - European Cultivated Potato Database (ECPD) - and another Brazilian - Embrapa 's Potato Cultivars Catalog 2015. The construction of maps, charts and procedures was made in the Microsoft Excel, in the Tableau 10.1 and with RTBMaps version 1.0 software. Salton's measure was used for data normalization. The results suggest that collaborative research conducted by networks can be more beneficial than individual research by avoiding overlapping studies, saving time and resources, and also connecting dispersed researchers. The continuity of agricultural development in developing countries, the lower cost of coordinated research and the investment in genetic improvement as a complementary tool to chemical control are also arguments that justify the benefits brought by these networks. Among the publications, the term "gene" was the one that predominated in the analysis of the density of terms. The authors of biotechnology, genetics, plant breeding and the development of resistant biotypes are those who collaborate most, as well as those with the largest number of publications, reaffirming the importance of breeding and cooperation for food security. In the germplasm exchange, Peru and Mexico have already been targets of numerous international expeditions - especially European countries - for the collection of materials. Still, most countries have connections with themselves higher than other countries, reinforcing the idea that national breeding programs work more closely with one another than with other countries. Germany and the Netherlands stand out against the other countries in relation to the number of resistant cultivars. Both also have the largest number of mutual collaboration, signaling the occurrence of bilateral agreements. India and China, despite being the world's largest potato producers, do not research on the crop. Overall, this study contributes to the identification of "who collaborates with whom" and confirms the importance of "working together" in solving collective challenges such as plant disease management. Together, the three articles show that cooperation plays a significant role in the genetic improvement of plants, being the essence of the networks, being prominent in publications in the area of genetic improvement and also for having a central role in the development of cultivars resistant to diseases. Thus, its implications make it possible to understand cooperation as a fundamental approach to the mitigation of plant diseases and the risks of global food insecurity.

KEYWORDS: Plant diseases; Food Insecurity; Agribusiness; Plant Breeding; Bibliometrics.

Tese de Doutorado em Agronegócios
Universidade Federal do Rio Grande do Sul

COOPERAÇÃO NA CIÊNCIA: O PAPEL DA COLABORAÇÃO CIENTÍFICA NO ESTUDO DE DOENÇAS EM TRIGO E BATATA

Autora: Lilian Cervo Cabrera
Orientador: Prof. Dr. Edson Talamini
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RESUMO

As doenças em plantas podem causar grandes perdas e representar um risco real para a segurança alimentar mundial. Para enfrentar esse desafio, a cooperação entre *stakeholders* do agronegócio é fundamental. Sendo assim, esta tese tem como proposta mensurar e analisar o papel da cooperação – colaboração científica – no manejo de doenças em plantas, especialmente no trigo e na batata. Para tanto, são apresentados três estudos que abordam tal temática. O primeiro estudo se propõe a caracterizar e estudar o funcionamento de algumas redes de pesquisa agrícola que monitoram patógenos, desenvolvem e distribuem cultivares resistentes a doenças e sequenciam o genoma do trigo e da batata. Nele, discute-se também como alguns patógenos podem ameaçar a estabilidade da produção de trigo e batata no mundo, especialmente o fungo *Puccinia graminis* f. sp. *tritici*, causador da ferrugem-do-colmo no trigo e o oomiceto *Phytophthora infestans,* causador da requeima na batata. Diferentes instituições como consórcios, centros de pesquisa e instituições estabelecidas são consideradas para ilustrar seu envolvimento em redes e para discutir suas atividades. O segundo artigo busca mensurar a colaboração científica nas publicações disponíveis na *Web of Science* por meio da análise de coautoria. O objetivo foi mapear os países que colaboram cientificamente na área de segurança alimentar. Foram considerados artigos publicados no período de 1996 a 2016 e os resultados analisados com o *software VOSviewer*. O terceiro artigo busca mapear os intercâmbios de germoplasma realizados pelos programas de melhoramento de batata no mundo para medir a colaboração entre países. Neste artigo, foram utilizadas informações somente sobre a batata. Cultivares de batata resistentes à requeima foram selecionadas com base em duas bases de dados, uma europeia – European Cultivated Potato Database (ECPD) - e outra brasileira - Catálogo de Cultivares da Batata da Embrapa 2015. A construção dos mapas, dos gráficos e os procedimentos de cálculo foram feitos no Microsoft Excel, no Tableau 10.1 e com o software RTBMaps. O Cosseno de Salton foi utilizado para normalização dos dados. Os resultados sugerem que pesquisa colaborativa conduzida pelas redes traz mais benefícios do que a pesquisa individual ao evitar a sobreposição de estudos, economizar tempo e recursos e também conectar pesquisadores geograficamente dispersos. A continuidade do desenvolvimento agrícola nos países em desenvolvimento, o menor custo de pesquisa coordenada e o investimento em melhoramento genético como ferramenta complementar ao controle químico também são argumentos que justificam os benefícios trazidos por essas redes. Entre as publicações, o termo “gene” foi o que predominou na análise da densidade de termos. Os autores das áreas de biotecnologia, genética, reprodução de plantas e desenvolvimento de biótipos resistentes são os que mais colaboram e também os que têm maior número de publicações, reafirmando a importância do melhoramento e da cooperação para a segurança alimentar. Nas trocas de germoplasma, o Peru e o México já foram alvos de inúmeras expedições internacionais – especialmente dos países europeus - para coleta de materiais. Ainda assim, a maioria dos países tem ligações consigo mesmos maiores do que com outros países, reforçando a ideia de que os programas de melhoramento nacionais colaboram mais entre si do que com de outros países. Alemanha e Holanda se destacam frente aos demais países com relação à quantidade de cultivares resistentes. Ambos apresentam também o maior número de colaborações mútuas, sinalizando a ocorrência de acordos bilaterais. Já Índia e China, apesar de serem os maiores produtores mundiais de batata, pouco pesquisam sobre o tubérculo. De maneira geral, este estudo contribui para a identificação de "quem colabora com quem" e corrobora a importância do "trabalho conjunto" na solução de desafios coletivos, como o manejo de doenças em plantas. Juntos, os três artigos demonstram que a cooperação tem papel relevante no melhoramento genético de plantas, por ser a essência das redes, ser destaque nas publicações da área do melhoramento genético e também por ter papel central no desenvolvimento de cultivares resistentes a doenças. Assim, suas implicações tornam possível entender a cooperação enquanto abordagem fundamental para a mitigação de doenças em plantas e dos riscos de insegurança alimentar mundial.

PALAVRAS-CHAVE: Doenças em plantas; Insegurança Alimentar; Agronegócio; Melhoramento Genético; Bibliometria.

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SUMMARY

CHAPTER 1:
INTRODUCTION

1. Study proposal

Cooperation can be defined as a joint action, a behavior that provides a benefit to another individual or is beneficial to both actor and receiver (TOMELA, 1993; MELLIS and SEMMANN, 2010). The cooperator is someone who pays a cost to receive a benefit (NOWAK, 2006). In nature, there are many examples of species co-operation, such as smaller fish that eat larger fish parasites and nitrogen-fixing bacteria that bind to the roots of plants (PENNISI, 2009). Among humans, carrying boxes to a friend, holding the door to a colleague, helping a blind man cross the street and donating blood are also some examples of cooperation. However, what makes unknown people cooperate with each other? Trivers in 1971 believed that cooperation between unknown persons would evolve if those involved gained immediate direct benefits from the interaction, or if the individual who invested to help others obtained a future benefit greater than the initial investment, eg. through reciprocity (MELLIS and SEMMANN, 2010). In science, these benefits can be associated with avoiding duplication of effort and involve, at a relatively low cost, a critical mass of researchers to solve specific problems (FARIS and PATANCHEER, 1991).

That being so, cooperation is nothing new. Coordination, collaborative research, networking and sharing of information and materials among researchers were used even before World War II in research centers in many developed countries (REMYI, 1987; PLUCKNETT et al., 1990, SILVA, 1997). For agriculture, co-operation has become an important approach to strengthening agricultural research in developing countries (NESTEL, 1985; OMRAN, 1988; FARIS and PATANCHERU, 1991; HAVERKORT et al., 1993; LAMICHHANE et al., 2016).

Given its diversity of proposals, forms and functioning, defining cooperation in agriculture - or collaborative agricultural research networks - is a challenge. Banta (1982) suggested that an agricultural research network is a voluntary association of research organizations with common goals sufficient to be willing to adjust current research programs and invest resources in network activities, believing that they will reach their goals in a more efficient way than to conduct all research alone. Dzowela

(1988) defined as a set of researchers or institutions linked by a common interest in working in a dependent or interdependent way on a problem or shared problems. Valverde (1988) extended the concept further and says that, in the broadest sense, agricultural research networks link individuals or institutions with a shared purpose in some kind of collaborative effort. Already Faris and Patancheru (1991) and Lamichhane et al. (2016) propose a simple definition that serves many forms of agricultural collaborative networks, including information networks, collaborative research networks and those that include field trials and extension of technology to farmers. An agricultural network is a group of individuals or institutions linked together because of the commitment to collaborate in solving a common agricultural problem or set of problems and to use existing (human and economic) resources more effectively. This definition includes researchers, technicians, extensionists and farmers, as well as national, international or regional donor institutions, government agencies and agribusiness enterprises.

From these definitions and considering the importance of cooperation for agricultural research, this study started from the hypothesis that scientific collaboration[1] between stakeholders (researchers, technicians, extensionists and farmers, as well as institutions, national, international or regional donors, government agencies and agribusiness companies) brings more advantages than individual research for agriculture. To illustrate this thesis, it is proposed, first, the study and characterization of the functioning of some agricultural research networks; followed by a bibliometric analysis (co-authoring analysis) of publications about wheat and potato crops and, finally, the mapping of germplasm exchanges carried out by potato breeding programs in the world.

1.1 General objective

The general objective of this study is to measure and analyze the role of cooperation - scientific collaboration – in network research, to identify in which areas it has been most intense and to point out implications and advantages of these collaborative efforts for the study of diseases in wheat and potato crops.

[1] The terms collaboration and cooperation are used here as synonyms to describe the efforts of two or more stakeholders working together. In the literature, there is no consensus on the use of the two terms. Some authors believe that collaboration is contained in cooperation, others argue that cooperation belongs to collaboration, however, most authors use the two terms indistinctly (BRESNEN and MARSHALL 1998, VAALAND 2004, THOMPSON et al. 2009).

1.2 Specific objectives

This thesis consists of three studies, each with specific objectives, but seeking to meet the above proposal. Thus, specific objectives can be considered:

a. To analyze major benefits of agricultural research networks in the study of diseases (rusts and late blight) in wheat and potato crops.

b. To map the countries that collaborate scientifically in wheat and potato crops, identifying the areas of research, the main groups of researchers and the themes that permeate the scientific universe of food security.

c. To map the germplasm exchanges conducted by potato breeding programs in the world to measure collaboration between countries.

1.3 Rationale

Many researchers have already warned that the future of science lies in collaboration, for stimulating multidisciplinary research and for expanding the frontiers of knowledge. Therefore, studying collaboration on the perspective of agriculture is justified by the identification of emerging or fragile areas of science that need support or should be incorporated into the guidelines of society's discussions for the solution of problems that affect world agriculture.

For this thesis, the study on wheat and potatoes and their contributions to world food security were delimited. Both are consumed directly and have gained importance in global diets, so both the stability of production and the availability of these foods to developing countries become increasingly critical issues. Both wheat and potatoes had increased their relative calories contributions in the diets of developing countries. While wheat increased its caloric intake by 23%, potatoes increased by 73% from 1969 to 2009 (KHOURY et al., 2014). These facts demonstrate the importance of wheat and potatoes for food security and justify the choice of both as the focus of this study.

Growing food dependence on wheat and potatoes suggests greater attention to the stability of food production. Because plant diseases can cause large losses in the productivity of these two staple crops, they can pose a direct threat to global food security. Thus, this study is justified in that it understands that global collaborative efforts (which aim to reduce losses in these two crops and diagnose risks, uncertainties, and opportunities) are examples of pro-food security actions that bring more benefits than research isolated. These benefits include: overcoming the scientific isolation of some countries and institutions, facilitating the sharing of research information and ideas, reducing duplication of effort and research, and speeding up scientific advances such as sequencing genetic. In addition, these global collaborative efforts can serve as anticipatory actions as they monitor the evolution of pathogen populations on a continental and global scale and can identify and exchange sources of resistance around the world. For developing countries, collaboration can mean more resources to be invested in agricultural research; to developed countries, can provide greater genetic diversity. Finally, this study is justified by providing a better understanding of cooperation, an important agribusiness theme, and its association with studies on plant diseases. Considering that scientific advance is based on theoretical constructions and empirical evidence, this study contributes mainly to the search for evidences that corroborate the importance of "joint work" for continuity of construction of knowledge related to science collaboration.

1.4 Metodological aspects

Considering the importance of cooperation for agriculture, we sought to analyze and measure scientific collaboration in three different ways: 1) characterizing and studying the operation of some agricultural research networks. 2) through a bibliometric study (co-authorships analysis) of publications in the field of food security (wheat and potato crops). 3) mapping the germplasm exchanges carried out by potato breeding programs in the world.

On chapter two, the paper entitled "Cooperation in agriculture: the role of agricultural research networks in mitigating the impact of wheat and potato diseases." aimed to know the benefits of networking in agricultural research networks that manage diseases in wheat and potato crops. It is discussed here how pathogens can threaten the stability of wheat and potato production in the world, especially wheat stem rust (caused by the fungus *Puccinia graminis* f. sp. *tritici*) and potato late blight (caused by the oomycete *Phytophthora infestans*). This study aims to discuss how collaborative research conducted by networks can be more beneficial than individual research. For this, we considered networks that aim to monitor wheat stem rust and potato late blight, to develop and distribute cultivars resistant to these diseases and to sequencing the wheat and potato genome. In wheat, the International Maize and Wheat Improvement Center (CIMMYT), the Borlaug Global Rust Initiative (BGRI), the International Wheat Genome Sequencing Consortium and the Global Cereal Rust Monitoring System (GCRMS) are presented. In potato: the International Potato Center (CIP), Euroblight, USABlight, the Global Initiative on Late Blight (GILB) and the Potato Genome Sequencing Consortium. (PGSC). This study discusses how collaborative research conducted by networks can be more beneficial than individual research.The third chapter, entitled “What about scientific collaboration in agriculture? A bibliometric study of publications about wheat and potato (1996-2016).” It has as main scope to measure cooperation - scientific collaboration - through co-authorships analysis in the scientific field of agriculture, specifically related to wheat and potato crops. In it, we considered articles published in the period of 20 years (1996 to 2016) and available in the Web of Science. Thus, the TS field (Topic) was used, referring to the research theme and the following search expression was constructed: TS = (agri* AND food security AND wheat OR potato). The results were analyzed using VOSviewer software. O The software allowed the construction of maps of the most recurrent terms (co-occurrence of words) in the scientific production of the food security area, as well as maps of the authors, countries and institutions that collaborate most in the area.

The fourth chapter, entitled "Potato breeding by many hands? Measuring international collaboration through the germplasm exchange between countries.” maps the germplasm exchanges carried out by the potato breeding programs in the world, with the goal of measuring collaboration between countries. Cultivars of potato resistant to late blight were selected based on two databases, a European - European Cultivated Potato Database (ECPD) - and another Brazilian – Embrapa’s Catalog of Cultivars of Potato 2015. From these bases, the necessary germplasm exchanges in the crosses and carried out between the countries served as an instrument to measure the international collaboration in the development of cultivars resistant to late blight. International collaboration maps were built in Tableau 10.1 and the graphs and calculation procedures were performed using Excel and RTBMaps version 1.0 software. In terms of quantitative indicators, this study used Salton's measure to normalize data, which is considered an indicator of the strength of mutual collaboration between two countries (GLÄNZEL et al., 2009; ALI-KHAN et al., 2013). In this article, we only used potato information, since the majority of potato cultivars are derived from two progenitors. In case of wheat, the use of two parents is not sufficient to provide the cultivar with the necessary combination of characteristics. Some wheat cultivars may have up to ten different parents, making it difficult to trace their country of origin.

CHAPTER 2:
COOPERATION IN AGRICULTURE: THE ROLE OF AGRICULTURAL RESEARCH NETWORKS IN MITIGATING THE IMPACT OF WHEAT AND POTATO DISEASES.[2]

Abstract

Wheat rust and potato late blight can cause heavy losses and pose a real risk to global food security. The formation of agricultural research networks is an example of a coordinated approach to address these challenges. We discuss how collaborative research conducted by networks can be more beneficial than individual research, since it avoids overlapping studies, saves time and resources, and also connects geographically dispersed researchers and countries. Among the networks, we analyze those that aim to monitor pathogens, develop and distribute resistant cultivars and sequence the plant genome. The continuity in agricultural development in developing countries, the lowest cost of coordinated research and the investment in genetic improvement are arguments that justify the benefits brought by these networks.

Keywords: Plant health; Agricultural production; crop losses; Science; *Phytophthora infestans; Puccinia graminis* f. sp. *tritici.*

1. Introduction

Worldwide, the occurrence of diseases in plants causes losses of millions of tons and also of dollars (Strange and Scott, 2005). Against this backdrop, FAO data show that the world population is expected to grow from nearly 7.5 billion to 9.1 billion people by 2050 (FAO, 2014). Thus, global food security depends on food production increase and on strategies developed by public and private sectors in order to use coordinated approaches to fight plant diseases. Among these approaches, agricultural research networks are noteworthy. Many of them aim, for example, to monitor diseases in plants, work together in genetic sequencing and development and distribution of resistant cultivars.

Thus, in order to discuss the importance of these networks for ensuring food security, this work is motivated by the question: what are the benefits of networking in agricultural research networks that manage diseases in wheat and potato crops?

To answer this question, we initially report the importance of wheat and potato crops to food security worldwide. Subsequently, it discusses how plant disease can threaten the wheat and potato production stability in the world. Finally, the role of some

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networks is exemplified and discussed. They are: the International Maize and Wheat Improvement Center (CIMMYT), the Borlaug Global Rust Initiative (BGRI), the International Wheat Genome Sequencing Consortium and the Global Cereal Rust Monitoring System (GCRMS), for wheat. In potato, we mention: the International Potato Center (CIP), Euroblight, USABlight, the Global Initiative on Late Blight (GILB) and the Potato Genome Sequencing Consortium (PGSC).

Agricultural research networks can be defined as a group of stakeholders or institutions linked together with a clear commitment to collaborate in solving one or more common agricultural problems through an effective use of existing resources (both human and economic) (Lamichhane et al., 2016). As it can have a diversity of purposes, forms, and operations (Faris and Patancheru, 1991); different institutions, such as consortia, research centers and established institutions are considered here to illustrate their involvement in networks and to attempt a discussion on their activities. Besides that, the choice of wheat and potato as objects of study is because they are, among the crops of direct consumption, the crops with the greatest increase in diets (Kearney, 2010; Khoury et al., 2014). In addition, they are the crops that suffer most losses due to the occurrence of diseases (Oerke et al., 2006).

2. Do wheat and potato matter for food security?

Wheat is an important cereal for global food security since it is an important source of calories and the main source of protein in more than 80 countries worldwide (FAO, 2003). In terms of calories, approximately 30% of the world population uses wheat and its derivatives as primary energy source. In addition, wheat accounts for 13-57% of the food energy intake depending on the country (Chaves et al., 2013). The world wheat production in recent decades increased from 222 million metric tons (Mt) in 1961 to 713 Mt in 2013, which represents 25% of the world grain production (FAOSTAT, 2015). By the other side, the wheat demand tends to increase, especially in developing countries. According to FAO (2003), by 2030, the world wheat demand will be 480 Mt only in these countries. The expected wheat demand by 2030 will be 851 Mt worldwide (FAO, 2003). Therefore, it is necessary to increase the world wheat production by approximately 20% over the next years.

In the case of potato, it is the food that shows the most significant increase in per capita consumption in developing countries (Alexandratos and Bruinsma, 2012). The high dependence of developing countries on roots and tubers as an important source of calories should continue: six countries in the sub-Saharan Africa will still depend on potatoes for more than 30% of the total food consumption (calories) by 2050 (Alexandratos and Bruinsma, 2012). Thereby, potato worldwide production increased from 270 Mt in 1961 to 368 Mt in 2013, thus representing 36% production increase in the last 42 years (FAOSTAT 2015). Following this breakthrough, the world population increased more than twice from 1961 to 2013 - from three billion to seven billion people - along with the per capita consumption of potatoes in developing countries. It is especially evident in China, wherein potato consumption levels rose from 25 g per capita per day in 1963 to 96 g per capita per day in 2003 (Kearney, 2010).

Both wheat and potato increased their relative calorie contributions to the diets in developing countries (Figure 01) (Khoury et al., 2014). From 1969 to 2009, wheat increased by 23% its caloric participation in diets, whereas potato increased by 73%.

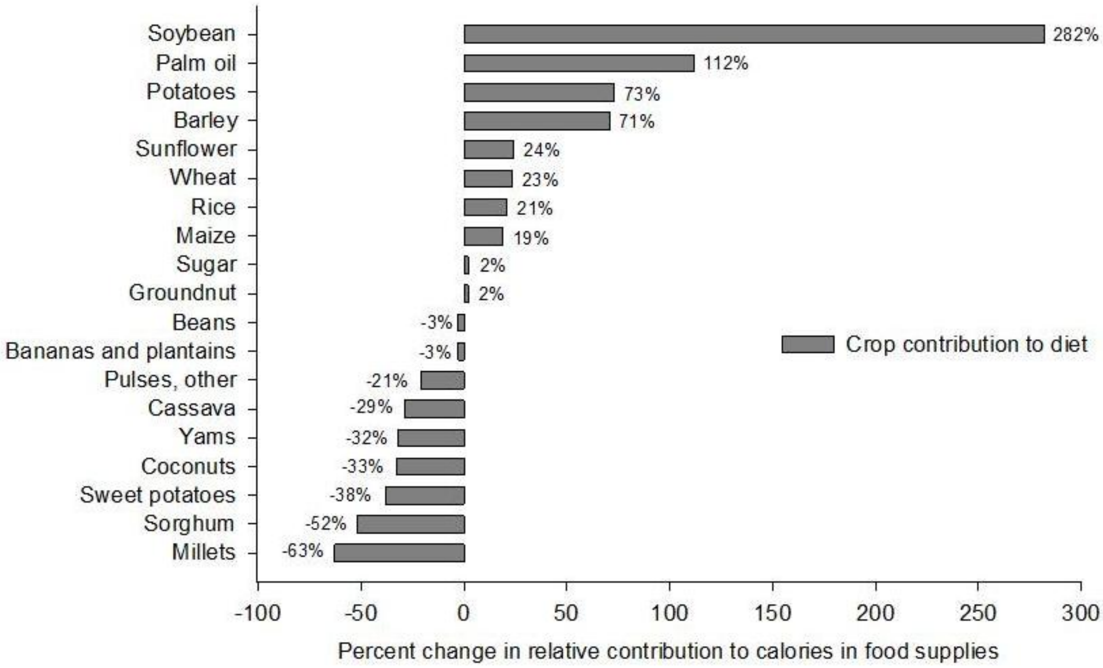

Figure 1. Percent change in relative contribution to calories in food supplies (1969-2009). While soybeans, widely used for cooking oil production, had the highest increase among foods analyzed, potatoes and wheat ranked third and sixth respectively. Foods such as pulses, cassava and sweet potatoes had consumption reductions. Source: adapted from Kearney (2010) and Khoury et al. (2014).

As the figure shows, the main cereals (wheat, rice and maize) continue to be sources of calories and proteins. Their relative contribution in the diets has gradually expanded in developing countries. The same happens in the case of potato and barley, which show the highest growth. Unlike oilseeds, these foods are directly consumed and any reduction in their supply may have negative impact on the countries' food security. The increased consumption of wheat and potato may be considered as indicative of enhanced food security, mainly with respect to food availability and accessibility in developing countries. However, the increasing food dependence on wheat and potato suggests that greater attention need to be paid to production stability of these crops. It implies not only the maintenance of these crops, but also their increase of productivity. Thus, it is worth emphasizing the importance of conducting studies about plant resistance to pests and diseases as well as to make global efforts to reduce the losses in these two crops.

3. Pathogens as a threat to food security and to the agricultural production stability

Among the six major crops in the world (wheat, rice, maize, potatoes, soybeans and cotton), wheat and potatoes are the crops that suffer most losses due to the occurrence of diseases (Oerke et al., 2006). Wheat and potato diseases result in millions of losses, measured both in tons and in monetary values (Table 1). In wheat, rusts deserve special attention, especially the stem rust. Caused by *Puccinia graminis* f. sp. *tritici* fungus, it has severely devastated wheat crops and is becoming the most feared disease in wheat producing countries from all continents (Singh et al., 2011). However, it was harmless for a long time in the past, since the *Sr 31* gene conferred resistance to all *Puccinia graminis* f. sp. *tritici* races. For over 30 years, using this gene did not result in major problems and its use was so widespread that nowadays it is present in almost 80% of the wheat grown in developing countries (Chaves and Almeida, 2012). However, given its ability to adapt, a new *Puccinia* fungus race that developed the ability to infect wheat plants with the *Sr 31* gene was detected in 1999, as well as other important resistance genes (CIMMYT, 2005). This new race was detected in Uganda, Africa, and named Ug99.

In the case of potatoes, the oomycete *Phytophthora infestans,* the cause of late blight, remains the greatest enemy of the crop in the world. It results in annual food losses that would be sufficient to feed hundreds of millions of people worldwide (Fisher et al., 2012). The oomycete quickly spreads from a plantation to another since it is transported by air. The infested potatoes literally rot before they were harvested. In 1840, the late blight was responsible for the great famine in Ireland, which catastrophically swept the country's potato fields and killed about one million people (Strange, 2003)

Table 1 - Estimated losses caused by wheat rusts and potato late blight worldwide.

Disease	Region	Period	Estimated losses	Reference
		Wheat		
Leaf rust	South America	1996-2003	$172 mi	German et al. 2004
Leaf rust	Australia	2009	AUD$12 mi	Murray and Brennan 2009
Leaf rust	Canada	2007	$80 mi	McCallum et al. 2007
Stem rust	Developing countries	2009	$1.4 bi	Dubin and Brennan 2009
Stem rust	North Africa; Asia Middle East and South	2012	$3 bi	BGRI 2012
Stem rust	Kenya	2007	$32 mi	Hodson 2009
Stripe rust	United States	2010	2.34 mi tons	Long 2011
Stripe rust	Pakistan	2005	$ 100 mi	Duveiller et al. 2007
Stripe rust	China	2002	1.4 mi tons	Wan et al. 2004
		Potato		
Late blight	North America; Europe (UK, France, Netherlands, Belgium, Germany, Scandinavia), Japan; Oceania	2009	€1.0 bi	Haverkort et al. 2009
Late blight	Worldwide	2008	$ 13 bi	Haverkort et al. 2009
Late blight	United States	1990-1998	$ 210.7 mi	Guenther et al. 2001
Late blight	Nepal	2009-2010	$ 104 mi	Sharma et al. 2013
Late blight	United States (Columbia basin)	1995	$ 30 mi	Johnson et al. 1997

4. The role played by agricultural research networks for food security

The following sections discuss how some strategies can be used to improve wheat and potato production stability by reducing the pressure of diseases. In order to illustrate these strategies, we bring examples of disease monitoring networks, wheat and potato genome sequencing, and sharing of research and information results. From these examples, we also discussed how the collaborative research carried out by these agricultural research networks can be more beneficial than individual research.

4.1 Wheat improvement in CIMMYT

For more than 50 years, an international collaborative network has made great contributions to improving wheat in developing countries. A global partnership called the Consultative Group for International Agricultural Research (CGIAR) currently comprises 16 International Agricultural Research Centers (IARCs), including the International Center for Agricultural Research in Dry Areas (ICARDA) established in Syria, in 1977, and the CIMMYT, established in 1965 (Reynolds and Borlaug, 2006). The latter, CIMMYT, has its history linked to the Office of Special Studies (OSS), a research project sponsored by the Mexican government and the Rockefeller Foundation, which has dedicated itself to the improvement of corn, beans, wheat and potatoes. The OSS began as a research and training program for Mexico but soon began to collaborate with other countries, especially South America. OSS developed the main organizational principles that would eventually become central to the entire CGIAR network (Ortiz et al., 2008).

For many decades, average global wheat yields have increased, supported by the International Wheat Improvement Network (IWIN), the National Agricultural Research Systems Alliance (NARS), CIMMYT, ICARDA and the Advanced Research Institutes (ARI). The benefits of this alliance for developing countries were substantial (Lipton and Longhurst, 1989; Evenson and Gollin, 2003). Thousands of modern wheat cultivars, including those resistant to diseases, were developed and millions of small farmers benefited (Reynolds and Borlaug, 2006). In the late 1950s and 1960s, researchers from Mexico, under the leadership of Borlaug, improved the spring wheat germplasm, which was responsible for the Green Revolution in India, Pakistan, and Turkey (Reynolds and Borlaug, 2006). In the 1990s, it was estimated that 90% of wheat grown in developing countries was derived from one or more CIMMYT varieties (Heisey et al., 2002). Currently, it is estimated that more than 75% of wheat planted area in developing countries uses cultivars developed by CIMMYT and its partners (CIMMYT, 2015).

The CIMMYT work proposal encompasses hundreds of national wheat research institutions that generate a mass dataset - produced by North and South partners (Ortiz et al., 2008). Collaborative research among the various partners around the world and the exchange of data between them increase the selection efficiency of rust-resistant wheat cultivars, for example. Briefly, the network coordinated by CIMMYT function as a wheel, where the outer edge represents the farmers, the central nucleus represents the researchers focusing on problems of global importance, and the rays represent the flow of wheat cultivars and information in both directions through collaborative researchers around the world (Reynolds and Borlaug, 2006).

CIMMYT is based in Mexico; however, the international winter wheat breeding program (Braun and Saulescu, 2002) is coordinated by Turkey, where CIMMYT works closely with researchers from its national program and ICARDA. In other words, CIMMYT is the center of the network, where institutional relations are promoted and maintained globally, not only through the exchange of germplasm, but also through the sharing of knowledge, training programs, international visits and the development of partnerships with other Organizations (Reynolds and Borlaug, 2006). Two of CIMMYT's main coordination responsibilities are the maintenance of the World Wheat Collection and the facilitation of Wheat International Nurseries (Reynolds and Borlaug, 2006).

CIMMYT operates in about 40 countries and is funded by international and regional development agencies, governments, private foundations and the private sector. Between 1990 and 2002, investments in the CIMMYT wheat breeding program were estimated at $ 6 million annually, while the attributed gains were on a global scale of $ 304 million, making cost-effectiveness close to from 50 to one (Nalley and Barkley, 2007). In addition, the international effort coordinated by CIMMYT has generated significant economic benefits in marginal environments - such as those affected by drought and heat stress in developing countries (Lantican et al., 2003; Ortiz et al., 2008).

4.2 BGRI and the replacement of susceptible cultivars

The Borlaug Global Rust Initiative (BGRI) (www.globalrust.org) is a collaborative effort, created in 2005. It is led by Cornell University and includes organizations such as the University of Minnesota, the University of California, Davis, the University of Sydney, the United States Department of Agriculture (USDA) and the Kenyan Agricultural Research Institute. It is also supported by ICARDA, CIMMYT, FAO and the Bill & Melinda Gates Foundation and has been formed to reduce the world's vulnerability to wheat rusts.

For the BGRI, substitution of susceptible wheat cultivars is the highest priority, especially in Africa and Asia, continents where Ug99 is already found (Joshi et al., 2011; Singh et al., 2011). Given the enormous rust destruction capacity and susceptibility to Ug99 - from about 90 to 95% of the world's wheat areas - substituting the area planted with these crops in Africa, the Middle East and Asia seems to be the best strategy to avoid large losses (Ortiz et al., 2008). The main strategies used by the BGRI are: monitoring and surveillance of Ug99, strengthening infrastructure and human resources in areas already identified with the disease, and the rapid development and distribution of resistant wheat cultivars. In most countries, especially in developing countries that lack a competitive seed sector, substitution of cultivars is a slow process (Evanega et al., 2014), which justifies BGRI's strategies.

Currently, BGRI has more than 1,000 partners in hundreds of institutions that work together to identify Ug99 resistant genes, including researchers from Brazil, Australia, Uruguay, Argentina and Chile, for example. Not all of these partners can be funded by BGRI. The resources are earmarked mainly for growing countries, especially in sub-Saharan Africa and other regions where there are poor farmers and vulnerable consumers (Coffman 2014 - personal communication[3]). As others networks, BGRI holds frequent international meetings, conferences and workshops in several countries. Such coordinated efforts are essential to facilitate interactions and collaborations between countries and regions. Meetings and conferences within and between regions facilitate the exchange of experiences, accelerate the development of cultivars and stimulate the exchange of knowledge and materials, as well as the transfer of technology.

4.3 The global rust monitoring system

Due to the events related to the emergence and spread of Ug99, a Global Grain Rust Monitoring System (GCRMS) has been established as another important strategy of BGRI and CIMMYT. The propagation of Ug99, mediated by wind or man, to countries other than Africa and Asia is evident. Models on the trajectories of the winds indicate that the movements of air from Kenya to southern Tanzania are a regular occurrence, particularly from January to March. Thus, infected wheat areas in the southern highlands of Tanzania can function as a source of rust spores for Zambia, Mozambique, Zimbabwe and South Africa (Singh et al. 2011). The presence of Ug99 in southern Africa has potential implications for other wheat producing regions, such as Australia or the Americas, although with a very low probability (Singh et al. 2011). Since April 2010, a global monitoring system for this fungus breed can be accessed on

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[3] Conversation held on October 9, 2014, during the "II Workshop Surveillance of Ug99 race in South America and wheat breeding for resistance" held in Porto Alegre, Brazil, lasting about half an hour.

the Rust Spore portal (http://rusttracker.cimmyt.org) in the three official languages of the United Nations (English, Arabic and Russian). The tool is a major effort to track the pathogen. It is supplied by researchers from partner institutions, which in turn connect with extension agents and farmers. At the beginning of the monitoring, there was no idea of the distribution of the disease by countries, especially African countries, since only a small number of partners provided data. Currently, more than 40 countries report the occurrences a central system, so that they are actually able to track the Ug99. Although in recent years the distribution of the disease is limited up and down the coast of Africa and Iran, if the spores spread, the tool should be able to detect it year after year (Coffman, 2014 - personal communication). Ug99 monitoring is essential for the early detection of epidemics and to facilitate timely responses. Only from the knowledge about the diversity and the epidemiology of the pathogen, it will be possible to construct disease control strategies in wheat.

4.4 International Wheat Genome Sequencing Consortium

For the development of resistant cultivars, the knowledge of the genetic map of crops is indispensable and this work is not done in isolation. Given the size and complexity of the wheat genome, sequencing requires a collective effort by laboratories and researchers. The International Wheat Genome Sequencing Consortium (IWGSCO) is an international collaboration consortium created in 2005 by a group of wheat growers, researchers and breeders to sequence the genome of wheat and make it publicly available. The IWGSC is a non-profit organization, registered in the United States, led by a board of directors, a leadership team and a coordinating committee. The board decides the overall strategy and the leadership team is responsible for the day-to-day management. The coordinating committee, composed of sponsors and project leaders worldwide, is responsible for establishing the global scientific strategy and strategic roadmap (IWGSC, 2016).

With over 1100 members in 55 countries, the purpose of the consortium is to establish a base for basic research and to enable the development of improved wheat cultivars (IWGSC, 2016). In January 2016, the consortium announced that more than 90% of the wheat genome had already been sequenced. This represents more than 97% of known genes and assigns information to the 21 wheat chromosomes. The achievement is commendable, but the project is not over yet. According to the IWGSC, the ultimate goal is a "gold standard" genome, a high-order sequence, which includes notating and identifying the precise locations of genes, regulatory elements, and markers along chromosomes. Driven by collaborative work and new technologies, genetic sequencing of wheat has advanced a lot in recent years (Bhalla, 2006). With the knowledge of the wheat genome, it will soon be possible to identify the function of each gene and what they encode. With such information, methods such as transgenic, and new molecular biology techniques such as gene modification, gene editing, and gene silencing may provide clues to increasing plant resistance in the future.

4.5 The Potato Genome Sequencing Consortium

In potato, the Potato Genome Sequencing Consortium (PGSC) sequenced the entire genome of the crop in 2011 (The Potato Genome Sequencing Consortium, 2011). This may accelerate the release of new potato cultivars, for example. The PGSC was started in January 2006 by the Plant Breeding Department of Wageningen UR (the University & Research Center) in The Netherlands, and during the course of the project became a global consortium with 29 research groups from at least 14 countries. Argentina, Brazil, China, Chile, India, Ireland, Netherlands, New Zealand, Peru, Poland, Russia, United Kingdom and United States are part of the consortium (Bryan, 2012). The Teagasc Crops, Environment and Land Use Research Center in the Netherlands, for example, contributed to the in-depth analysis of a region on chromosome 4, which houses genes that confer natural resistance to the blight and the cyst nematode, the two most significant limitations to production of potatoes in the world (Teagasc, 2011). For the understanding of the complete potato genetic map, efforts of different research groups were pooled. In addition, information on yield of different cultivars, physiological and morphological characteristics, nutritional value and resistance to diseases are analyzed and distributed to collaborators and the public through periodic reports that allow them to replicate, verify and broaden their research.

Knowledge of the complete potato genome has already led to the development of more than 10,000 new genetic markers. They are helping to analyze important characteristics of potato, such as disease resistance and tuber dormancy (Bryan, 2012).

4.6 The European and the American late blight monitoring systems

Just as in wheat, to support the genetic improvement of potatoes, it is worth highlighting the importance of monitoring the late blight in different countries. A European network - Euroblight (www.euroblight.org) - of scientists and other specialists working in the fight against late blight meets every 18 months to discuss about the disease. The network was formed in 2006, combining two previous networks (EU.NET.ICP and Eucablight) and has 150 members (Forbes, 2012; Euroblight, 2016). It is organized into sub-working groups: host-pathogen interactions and characteristics, epidemiology, decision support systems - DSS - and modeling, fungicides and management strategies and Alternaria (Euroblight, 2016). These working groups meet in the EuroBlight workshops to discuss new results, coordinate national projects and plan joint initiatives. The main current joint initiatives are the evaluation of fungicide efficacy and the monitoring of late blight in Europe (Lamichhane et al., 2016). Euroblight is also a platform with a climate-based DSS that uses information technology platforms and population typography protocols for pathogens. From this information, original data and analyzes on the evolution of pathogens are generated and disseminated. The aim is to improve DSS models and establish a reference network of laboratories able to track new emergencies in Europe (Lamichhane et al., 2016). Euroblight's pathogen monitoring model offers a fast, cost-effective and coordinated approach to the understanding of late blight on a European scale. Information on fungicide resistance, the evolution of *P. infestans* and the potency of dominant potato cultivars are regularly shared with farmers, consultants, breeders and agrochemical companies to assist in disease management in the field and to shape long-term strategies (Lamichhane et al. 2016). In addition, EuroBlight has contributed to the establishment of another similar network in North America, USABlight. Asia and Latin America have also more recently established their AsiaBlight and LatinBlight monitoring networks, with similar performance (Lamichhane et al., 2016). In the United States, USABlight does the monitoring of potato and tomato late blight. With the support of the USDA, the network includes 25 US researchers and a map of the occurrences of the disease in the country. There is also information about the disease, ways to identify it, and management strategies. USABlight was launched in 2010 to provide a means of communication between researchers and extensionists, producers, industry and consumers about the disease. Through the portal (www.usablight.org), visitors can learn about disease symptoms, examine disease reports, learn about disease management options, and submit samples for genotyping and fungicide testing (Saville et al., 2012). In addition, like Euroblight, it has a Potato DSS that allows the inclusion of National Weather Service weather forecasts to predict the need for future fungicide applications.

4.7 Potato improvement and information sharing in CIP

The International Potato Center (CIP) is a non-profit scientific institution founded in 1971 in Peru. Like CIMMYT, it is one of the 16 international research centers of the CGIAR. Since its inception, it has collected, preserved, developed and distributed potato cultivars to researchers and farmers around the world. The CIP potato collection is the largest in the world with wild and cultivated cultivars. Efforts to maintain this collection have long included collaboration between potato gene banks around the world (Huaman and Schmiediche, 1999; Bradshaw et al., 2006). CIP focuses on providing diversified and improved genetic material to the potato producing regions of developing countries. So that, national breeding programs can identify and develop cultivars adapted to local conditions. In 2007, breeding programs in 23 developing countries developed 681 new potato cultivars, of which 251 originated from CIP germplasm (ISPC, SPIA, 2010). CIP germplasm has been widely adopted in Africa, particularly in Ethiopia, Kenya, Rwanda, Tanzania and Uganda. Together with China, which has been using a blight-resistant potato cultivar (Cooperation 88), these countries were responsible for the growth of more than 85% of the world potato cultivation areas originating from CIP cultivars, between 1997 and 2007 (ISPC, SPIA, 2010). CIP researchers work closely with farmer's communities, providing disease-free cultivars (Scott, 2011). Among its main collaborative activities are the various contacts between CIP and extension organizations as a way to facilitate farmers' access to information and technology. Since 1992, CIP has also established a number of contacts with NGOs to disseminate their research results to more distant or resource-poor farmers (Ortiz, 2006). It is also a key role in establishing AsiaBlight and LatinBlight, both monitoring networks of *P. infestans* (CIP, 2015).

4.8 The Global Initiative on Late Blight

CIP is also responsible for the global network called the Global Initiative on Late Blight – GILB - (Forbes, 2009). It is a platform (https://research.cip.cgiar.org/confluence/display/GILBWEB/Home) formed by researchers, technology developers and agricultural knowledge agents. The goal is to exchange ideas and opinions and facilitate communication and access to information on potato late blight. Its main information concerns the development of resistance and studies on the management of the disease. Although GILB incorporates partners around the world, its main goal is to improve the management of late blight in developing countries. The initiative began in 1996 and three international conferences have been held since then, the last in Beijing in 2008 (Forbes, 2012). Through these meetings and the web page, GILB has been a useful tool to help researchers increase knowledge of late blight management in developing countries.

5. Characterization and operation of the networks

Briefly, characterization and operation of the networks presented here can be visualized in Figure 2.

			Research and Communication	**Assets**	**Members and Coordination**
	Actor	**Type of network**	**Roles**	**Funding sources**	**Members and coordination**
Wheat	CIMMYT	International Agricultural Research Center	**Development and exchange of wheat germplasm**, sharing of knowledge, training programs, international visits and development of partnerships with other organizations.	International and regional development agencies, governments, private foundations and the private sector.	It has over 1,200 employees based in 17 countries worldwide. It leads the CGIAR Research Programs Maize and Wheat, aligning research goals among more than 500 partners.
	BGRI	International consortium	**Monitoring** and surveillance of Ug99, strengthening infrastructure and human resources, **development and distribution of resistant wheat cultivars**.	ICARDA, CIMMYT, FAO and the Bill & Melinda Gates Foundation	It is led by Cornell University and includes organizations such as others universities, the USDA and the Kenyan Agricultural Research Institute. BGRI has more than 1,000 partners in hundreds of institutions that work together to identify Ug99 resistant genes.
	GCRMS	CIMMYT and BGRI strategy	**Global monitoring** system for rust.	CIMMYT and BGRI	It is supplied by researchers from partner institutions in more than 40 countries.
	IWGSC	International consortium	**Sequence the genome of wheat** and make it publicly available.	Itis a non-profit organization, registered in the United States.	It is led by a board of directors, a leadership team and a coordinating committee. IWGSC has over 1100 members in 55 countries.
Potato	PGSC	International consortium	**Sequence the genome of potato**.	Each partner performs their sequencing projects on funding from their own resources.	It has 29 research groups from at least 14 countries.
	Euroblight	European consortium	Evaluation of fungicide efficacy and **monitoring** late blight in Europe.	Private sector	Researchers in the Netherlands, Scotland, Denmark and France, working with partners from research labs and industry.
	USABlight	American consortium	Evaluation of fungicide efficacy and **monitoring** late blight in USA.	USDA	25 US researchers provide information through a portal to others researchers and extensionists, producers, industry and consumers.
	CIP	International Agricultural Research Center	**Providing** diversified and improved **genetic material** to the potato producing regions of developing countries.	International and regional development agencies, governments, private foundations and the private sector.	Members include 25 developing and 22 industrialized countries, four private foundations, and 13 regional and international organizations.
	GILB	CIP strategy	Exchange ideas and opinions, facilitate communication and access to **information on potato late blight**.	CIP	It is a platform formed by researchers, technology developers and agricultural knowledge agents.

Figure 2. Characterization and operation of the nine agricultural research networks.

Agricultural research networks make it possible for researchers with the same interests, but geographically dispersed, to communicate and coordinate their actions through global networks to exchange knowledge. However, how do we know if agricultural research networks bring benefits in relation to isolated research?

First, the question of how much it would cost for each national program to develop its own technologies is a very powerful argument in favor of agricultural research networks (Reynold and Borlaug, 2006). In a time of increasing globalization, internationally coordinated research makes perfect sense, provided it remains focused on broader issues, which seek to solve global problems, such as blight and rust. Networks for genome sequencing stand out in this regard, as they publicly disclose their progress, directing and stimulating the progress of other breeding programs.

Nowadays, the private sector is a major funder of agricultural research networks (Alston et al., 2009). Although it is not possible to measure the real intent of these investments (ranging from commercial interests to increasing their tax incentives), this is what happens with most networks mentioned above. In general, it supports the idea of agricultural research networks as an internationally funded public goods organization (CIMMYT, 2004). There is participation of the private initiative, but the information and results are considered public goods, and distributed freely to the public, as well as the cultivars developed. In addition, some networks are already approving regulations on property rights of their research findings. According to them, this is a way to prevent private companies from patenting their discoveries or resources and a guarantee that they can continue to be distributed freely to everyone (Dalton, 2000).

In the case of cultivar distribution, for example, the time required between development and farmers' access to these cultivars could be a constraint on the work of the networks. An alternative would be to establish agreements between agricultural research networks and seed distributors or extension companies in each country to reduce that time (Forbes, 2012). These agreements are not simple and may involve patent rights and laws to regulate the entry of seeds into each country, which may take time to resolve too. As an alternative, CIP, for example, opts to work with participatory methodologies among farmers in Peru, Bolivia, Ethiopia and Uganda to encourage the adoption of new cultivars and facilitate such procedures. CIP works as a "connector", facilitating farmers' access to technologies, methods and opportunities, and linking research and development to farmers in the four countries (Ortiz et al., 2013). In contrast, USABlight in the United States and Euroblight in Europe operate locally in the monitoring of *P. infestans*. They offer farmers decision support systems that can be used to calculate late blight risk for each specific country. The system provides information on the number of sprays and also a table of fungicides with all the important characteristics of the products. Sometimes the number of applications can be reduced in relation to climatic conditions and / or resistance to the cultivar used by each farmer in each region. As such, it is an important tool locally and regionally, which in the future may be an interesting option for other countries and regions. In contrast, CIMMYT and BGRI, both CGIAR's arms, operate mainly in countries in Asia and Africa, far from central offices. As CGIAR is basically supported by grants, investors want to see evidence of impacts on development goals, such as reducing poverty and hunger. For them, these metrics demonstrate that research investments represent money well spent (Renkow and Byerlee, 2010). Thus, investing in countries where there are few resources - infrastructure and precarious extension services, - but great potential for food production has a greater impact on reducing hunger and world poverty. Moreover, Europe has encouraged the European Union's collaboration with all sectors and nations as well as with developing countries. This collaboration is also observed at the global level, notably in the United States, for reasons motivated by the demands of science (Leydesdorff et al., 2013; Virgin and Morris, 2016). In addition, economic and political objectives often contribute to international collaboration with developing countries, particularly those in Africa, in order to reduce the North-South technological divide and ensuring access to advanced technologies (Virgin and Morris, 2016).

A second argument would be that, in considering food security, agricultural research networks provide continuity in agricultural development. Otherwise, this could be uncertain for a large number of developing countries. Although many agricultural research networks are based in developed countries, Latin America, Africa and Asia end up being the biggest beneficiaries of their results. As chemical control is still the most commonly used way to control disease in crops, farmers in more capitalized countries are able to carry out routine fungicide applications, but small profit margins for farmers in developing countries often prevent the use of these inputs. In wheat alone, the cost to protect one hectare of the crop through the application of fungicides can range from $ 10 to $ 18 per hectare, or about $ 3.5 billion worldwide (Joshi et al., 2011; Brennan, 2009). Meanwhile, an annual expenditure of $ 51.1 million in research on wheat rust, for example, would be equivalent to investing $ 0.23 per hectare of wheat (Pardey et al. 2013). For this reason, pathogen monitoring and the development of disease resistant cultivars may particularly favor these farmers. Thus, although chemical control is still essential to stop the spread of disease throughout the world, initiatives that treat genetic improvement as a complementary and perhaps more accessible tool to poor farmers should be encouraged. Finally, it is worth noting that these agricultural research networks hold many meetings, both international and project-based, in addition to joint fieldwork, study visits and field days with farmers. Through these meetings, it is possible to group resources and capacities for research and extension, as well as share knowledge and experiences. All these are levers for the partners to remain mobilized and motivated in the networks, calling attention to a problem and acting on it and its solutions, that is, practicing advocacy (Quiroz, 2005; Jaramillo López, 2011).

6. Concluding remarks

Given the devastating effect of rust and late blight on wheat and potato, they may pose a threat to the four dimensions of food security, namely: food availability, stability, access and use (Reynold and Borlaug, 2006; Schmidhuber and Tubiello 2007; Chaves et al., 2013). Thus, keeping the yield increase rates needed to meet future demands will require a sustained effort to develop wheat and potato varieties resistant to these diseases. In food security, the concrete results are the prevention of disease and pest outbreaks, the faster genetic sequencing studies and the anticipation of impact mitigation and control strategies.

Among the benefits of these agricultural research networks, there is the fact that they are more viable to combat epidemics in plants than chemical control (Haverkort et al., 2009; Joshi et al., 2011; Dubin and Brennan, 2009); they indirectly act in reducing the use of fungicides as well as the potato and wheat production cost. Besides that, the gains attributed to agricultural research networks are much larger than the investments (Evenson et al., 1979; Alston et al., 2000; Evenson, 2002; Alston et al., 2009). Although it takes a long time and may be subtle, the agricultural research typically affects productivity for many decades. Much investment in agricultural research is of a "maintenance" type, designed not to increase yields so much as to prevent yields from declining in the face of coevolving pests and diseases, for instance (Ruttan, 1982; Alston et al., 2009). Without constantly investment in maintenance research, crop productivity and stability would eventually decline. The valuation of agricultural research is therefore incomplete without accounting for the losses that would have occurred in the absence of its maintenance component. Thus, the agricultural research networks avoid overlapping studies, save time and research resources, and also allow the exchange of information and services among geographically dispersed researchers. In addition, these global collaborative efforts can serve as anticipatory actions as they monitor the evolution of pathogen populations on a continental and global scale and can identify and exchange sources of resistance around the world. For developing countries, collaboration can mean more resources to be invested in agricultural research; to developed countries, can provide greater genetic diversity. In this way, collaboration is a way to add capabilities and smooth bottlenecks in different countries.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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CHAPTER 3:
WHAT ABOUT SCIENTIFIC COLLABORATION IN AGRICULTURE? A BIBLIOMETRIC STUDY OF PUBLICATIONS ABOUT WHEAT AND POTATO (1996-2016).[4]

Abstract

In evolutionary biology, the ability to cooperate may have determined the success of the human race over other races. In agriculture, it seems to be the key to increasing agricultural productivity to feed nine billion people. Thinking about it, the main scope of this work is to measure the cooperation - scientific collaboration - through the co-authorships analysis in the agriculture field of literature. The goal was to map the countries that collaborate scientifically in the food security area. We considered articles published in the last 20 years in Web of Science and the results were analyzed using the VOSviewer software. The results indicate that the gene (the term "gene") was the predominant theme in the density of the terms in the articles and also in the studied subjects. The United States is the country that most contributes, followed by China. These two countries also have the largest mutual collaboration, with 254 connections between them.

Keywords: cooperation, co-author, co-occurrence, indicators, agribusiness, bibliometrics.

1. Introduction

In a series of recent studies comparing human beings with lower primates, scientists do not hesitate to link the success of human evolution to the ability to collaborate (Nowak, 2006; 2012; Despain, 2010). According to social anthropologist Kim Hill, humans are not special because of their brain size. That's not why space rockets are built, no one could do it alone, she says. There are rockets because 10,000 people cooperate to produce information (Wade, 2011).

In Hill's view, the two main traits that sustain human evolutionary success are the unusual capacity for cooperation between people without family ties and the social learning, i.e., the ability to copy and learn from what others are doing. With these two skills, a large social network can generate knowledge and innovations much more easily than a cluster of small isolated groups (Wade, 2011).

If cooperation and social learning were able to determine the success of one race over others over thousands of years, wouldn't these two skills, even today, be the lever for the globalization of some areas of knowledge? Wouldn't they be key elements

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for advancing sequencing and knowledge of the human and other genetic map (genome), or for ensuring global food security? In agriculture, according to a report by twelve G20 countries, some progress is being made, but much more can and should be done in support of a more productive and sustainable system of food production. According to the report, collaboration is the key to increasing agricultural productivity to feed nine billion people in the future (Organization for Economic Cooperation and Development, 2012).

In any case, even if the answers to these questions are positive, how can we measure cooperation? What metrics could be used to measure cooperation between people and also if it has been generating social learning and scientific advancement, especially for agriculture around the world?

Thinking about this, the main scope of this work is to measure cooperation - scientific collaboration - through the co-authorship analysis (a technique widely used in bibliometrics studies) in the agricultural literature. Thus, the objective of this article is to map authors, institutions and countries that collaborate more scientifically in food security. For this, articles published in the last 20 years (1996 to 2016) of the Web of Science database were considered and the results analyzed through VOSviewer software.

2. Scientific collaboration and bibliometrics studies

Collaboration is a social process and human interaction that can happen in different ways and for different reasons (Vanz, 2009). In nature, among animals, there are many examples of collaboration between species, such as smaller fish that eat larger fish parasites and nitrogen-fixing bacteria that bind to the roots of plants (Pennisi, 2009). Over the decades, biologists have been discussing cooperation, striving to understand it in the face of evolutionary theories.

In the main dictionaries, the word collaboration means "to cooperate, to help". The concept is broad and, in the case of scientific collaboration, there is still no consensus on how to measure help between scientists. In classical understanding, two people collaborate when they share data, equipment and/or ideas in a project, which usually results in publications (Katz and Martin, 1997). However, a person can also be considered a contributor by providing materials and assisting in trials (Vanz, 2009).

In the literature, scientific collaboration often appears related to co-authorship. Katz and Martin (1997) evaluate that co-authorship is not synonymous of collaboration, because authors are not always responsible for the work. In addition, not all collaboration between scientists results in publications. Despite this, co-authorship has been widely used by bibliometrics to study collaboration between people, institutions and countries. The same authors cite as advantages of co-authoring, the possibility of checking the data by other authors and the ease and practicality with which the method allows the analysis of large samples, allowing more significant results than case samples (Katz and Martin, 1997). Bibliometrics can be described as an area of knowledge that focuses on quantitative measurement of science production. Much has been discussed about measurement, characterization and evaluation of science, that is, about evaluation of research results of scientists and scholars, who have their product presented in different ways.

3. Methodology

This study is an exploratory research and the source used was the Web of Science (WoS), a multidisciplinary database of Thomson Reuters, used worldwide for the analysis of scientific production. There was a restriction on the type and period of publications, so only articles published from 1996 to 2016 were searched. In the data collection, the option of advanced search was used, which allows the use of Boolean logic. The research was carried out with the Proxy of Federal University of Rio Grande do Sul (UFRGS) and the keywords were chosen with the purpose of analyzing the characteristics of the publications of the area of agriculture related to the theme of food security. As an integrant part of a doctoral research - which investigates the role of scientific collaboration as a disease mitigation strategy for wheat and potatoes, in particular - the research was limited especially for these two crops. Thus, the field TS (Topic) was used, referring to the topic of the research and the following search expression was constructed: TS = (agri * AND food security AND wheat OR potato). Considering the large number of publications found, it was decided to refine the research by categories of the Web of Science that would encompass food safety issues. Thus, only articles belonging to the 15 major categories below were selected: (Plant Sciences OR Agronomy OR Food Science Technology OR Biochemistry Molecular Biology OR Agriculture Multidisciplinary OR Biotechnology Applied Microbiology OR Chemistry Applied OR Entomology OR Horticulture OR Nutrition Dietetics OR Genetics Heredity OR Environmental Sciences OR Microbiology OR Engineering Chemical OR Multidisciplinary Sciences).

Data collection was performed on July 2, 2016 and 18,998 articles were found. The data was imported from the Web of Science into txt format files. The VOSviewer software, developed by the Center for Science and Technology Studies of the University of Leiden, The Netherlands, was used to organize and analyze the data (Van Eck and Waltman, 2010). The tool allows the organization and the accomplishment of descriptive analyzes of bibliographic records extracted from databases such as WoS.

The objective of the analysis of this article is to measure the scientific collaboration in the area of food safety. From its measurement it is possible to identify international collaboration networks, as well as to map the evolution of the different fields of science and technology to food security.

4. Results and discussions

The results showed 18,998 articles relating the terms "agri*", "food security" and "wheat" or "potato" in journals of the selected categories. The first analysis was the co-occurrence of words, with the objective of identifying contents that could directly or indirectly indicate the relationship of these terms with the different scientific fields that can be encompassed by food security. Figure 1 shows a map of the words that most occur in the titles and abstracts of the articles.

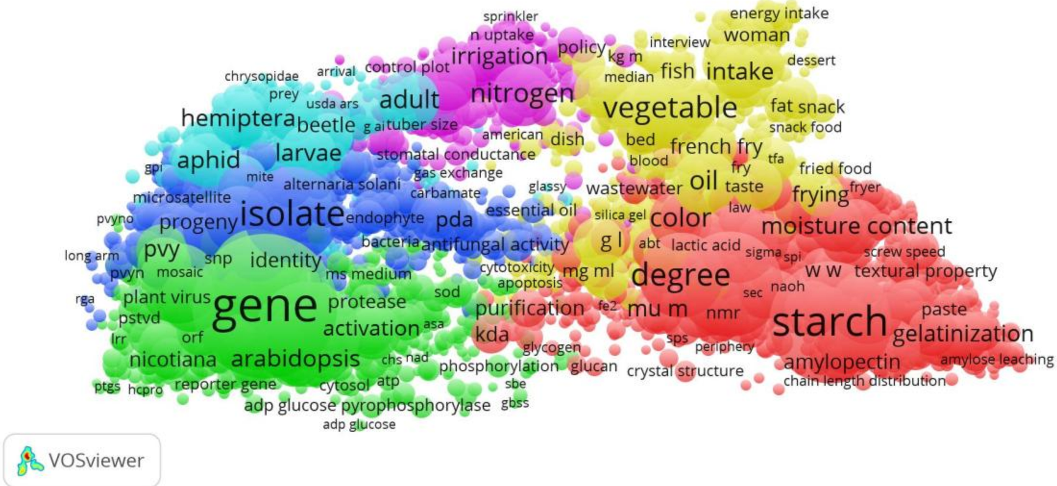

Figure 1 - Map of the words that occur in the titles and abstracts of the analyzed articles.

It is possible to note that in the map, there is the presentation of the words in groups or clusters (defined by color) and different sizes. This method identifies clusters of words that appear together in titles, abstracts or full texts of publications (Callon et al., 1986). According to him, if two or more words are quoted together in a publication, these words are related. The greater the number of times they occur together, the greater the strength of co-occurrence. In this way, it is possible to identify the most frequently used terms in research topics.

In the map above, it is observed that six clusters are identified and those that appear next share high similarity, whereas the clusters more distant denote low similarity. Each constituent circle of the network is one of 4720 words that had 12 or more occurrences. VOSviewer software selected these 4720 words, or 60% of the most relevant terms in the titles and abstracts of articles reviewed and identified 688,039 links between these words. The words "gene" and "starch" are the ones that appear in larger size, and occurred 2703 and 1930 times, respectively, in the articles analyzed. In the cluster of green color, in which the word "gene" appears, they appear related to it, words like "protease", "plant virus", "mosaic", "activation". In the cluster of red color, linked to the word "starch", also appear words like "moisture content", "amylopectin", "textural property". In addition, other words appear in three other clusters of different colors, like: "vegetable", "intake", "food", "taste" (in the yellow cluster); "Nitrogen", "irrigation", "uptake" (in the pink cluster); "Larvae", "adult" (in the light blue cluster) and "isolate", "progeny" and "molecular marker" (in the dark blue cluster).

Thus, it is understood that in the green cluster as in dark blue, the focus of the publications is on genetics, the light blue color is on insects and pests. In the pink cluster the focus is on the agricultural management, the yellow one is on diets and food patterns, while in the red cluster is on chemical and organoleptic characteristics of food. In addition, the VOSviewer software pointed out that, of the 4,720 words, 24% of them (1130 words) occurred in the red cluster articles, that is, they had terms referring to the chemical and organoleptic characteristics of the foods. The green and dark blue clusters, that deal with genetics, performed together 40% of the words found (965 to 959 words, respectively), as the light blue cluster, which deals with insects and pests, showed 9% of the words found, while the pink and yellow clusters, which deal with agricultural management and diets and food patterns, presented 13% and 14% each.

In Figure 2 we can observe the density of the terms. The red color indicates higher density, which means that these words have greater weight or interest; followed by orange, yellow, green and blue colors. Therefore, genetics (the term "gene") stands out as the main focus of discussions during the analyzed period.

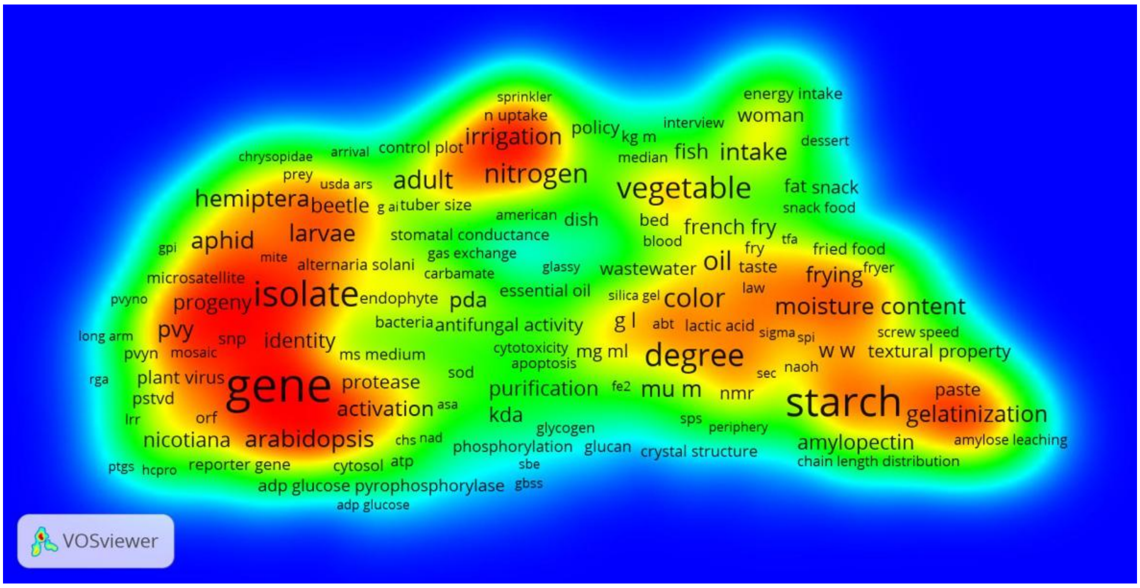

Figure 2 - Density map of the words that occur in the titles and abstracts of the analyzed articles. The red color indicates higher density, which means that these words have greater weight or interest; followed by orange, yellow, green and blue colors.

As this visualization is indicated for a quick identification of the most important areas of the map, Figures 3 and 4 allow identifying the terms that were searched together with the most used words and that were presented in Figure 2. In other words, they explain the stronger relationships of the main themes, namely, those who were most often studied together. In Figure 3, the composition of a cohesive group of words around the term "gene" is shown.

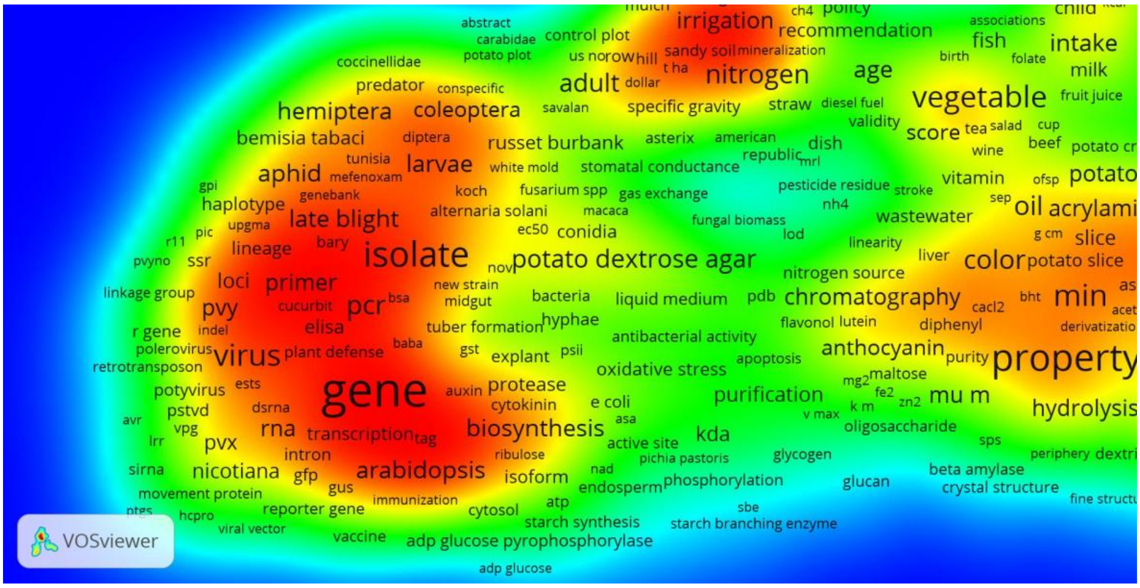

Figure 3 - Density map highlighting the word "gene" that occurs in the titles and abstracts of the articles analyzed. The red color indicates higher density, which means that these words have greater weight or importance; followed by orange, yellow, green and blue colors.

The words "isolate", "virus", "late blight", "primer" and "PCR" appear in particular. They refer to the technique used in molecular biology and plant breeding (Polymerase Chain Reaction - PCR) and plant diseases (late blight and Y virus). In potato and tomato, for example, late blight and Y virus can compromise all production. Genetic improvement (and the development of resistant cultivars) has been pointed out as the best way to control them, justifying the interest in the subject and, consequently, the great occurrence of these terms in the publications.

Figure 4 shows the composition of a smaller, but also cohesive, group of words around terms such as "irrigation", "nitrogen" and "field experiment", which refer to the management of agricultural crops.

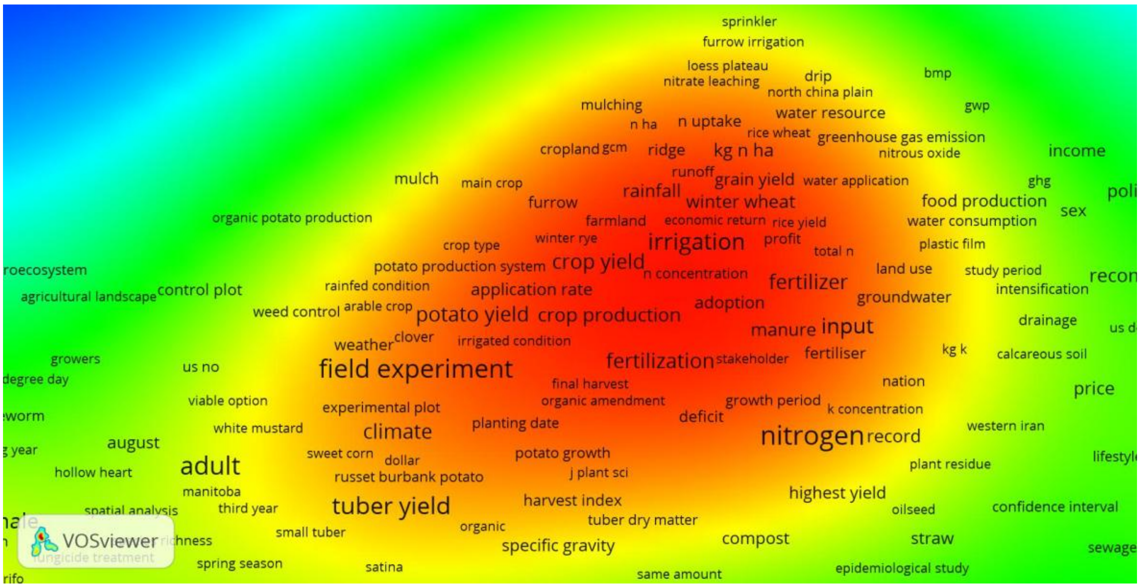

Figure 4 - Density map highlighting the word "irrigation" that occurs in the titles and abstracts of the analyzed articles. The red color indicates higher density, which means that these words have greater weight or importance; followed by orange, yellow, green and blue colors.

Linked to them are the words "fertilization", "winter wheat", "potato yield", "input" and "climate". All of these are terms indicate that the production factors and the wheat and potato management practices are highlighted themes in the published articles. It is observed that this group portrays the discussions related to food production, related to agriculture, yield and crop efficiency and the resources needed for its production, such as water and fertilizers. In addition to the necessary conditions for food production, it also highlights irrigation, and climate-related implications, issues from the perspective of food security. After the construction of the terms maps of the scientific production of the area, the results of the scientific collaboration of the authors, countries and institutions of the area are presented below. At a micro level, the authors are the producing individuals and agents of science; And at a higher level, research agents are the institutions to which they are a part, and consequently the countries to which those institutions belong. From a total of 49,198 authors, the map in Figure 5 shows 2937 of them, that is, those who have at least five published articles.

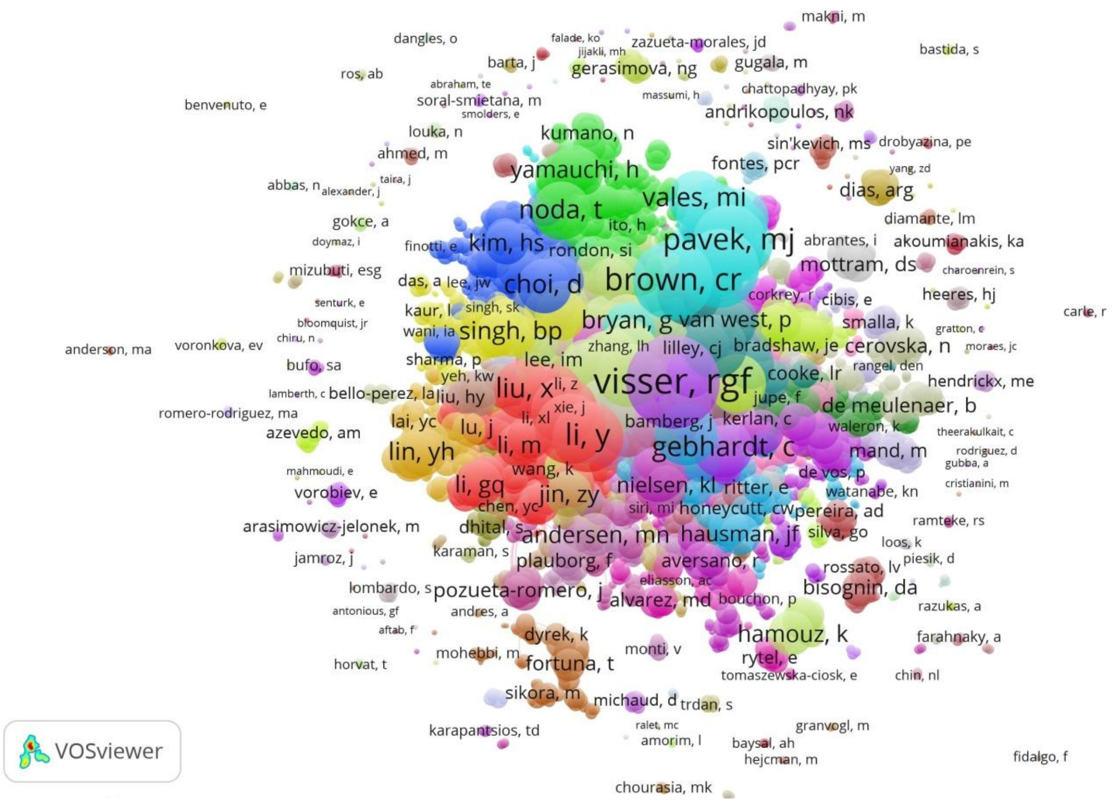

Figure 5 - Map of the collaboration of the main authors of the analyzed articles.

According to the software, the authors are divided into 220 different clusters and there are 17,816 connections between them. The largest cluster has 436 authors and is identified on the map by red color. The central author of this cluster (Li, Y.) has 61 publications and 210 collaborations. With the largest number of collaborations in the red cluster, his work investigates the impacts of agricultural practices on the environment and also fertilization and irrigation in cropping systems such as wheat, corn and rice. Throughout the map, the most productive author (Visser, RGF) has 106 articles and 493 collaborations in his works. He is the author with the largest number of publications and also with the greatest collaboration of all the clusters. Richard Visser is professor at the Department of Plant Sciences, on Wageningen University and Research Plant Breeding, the Netherlands. His works are focused on biotechnology, genetics, molecular biology and plant breeding and he is the central author of the purple color cluster. In the light blue cluster, there is also another author (Brown, CR) who stands out with 56 publications and 355 collaborations. He is the lead author of this cluster and research on plant breeding, especially potato, and resistance of these plants to fungi, nematodes and viruses. Charles Raymond Brown is researcher at the Temperate Tree Fruit and Vegetable Research Genetics, on USDA/ARS, Prosser, Washington, United States. In the other clusters, there is no one author who stands out from the others, nevertheless, the map shows a strong link between authors within each cluster. If an overall average is made (of the 220 identified clusters and the connections between the authors), it can be said that each map cluster has about 80 collaborations, so each author would have, on average, six collaborations. As the number of collaborations is not the same in all clusters or for each author, in Figure 6 is possible to observe the density of the clusters and to identify those with the greatest number of collaborations.

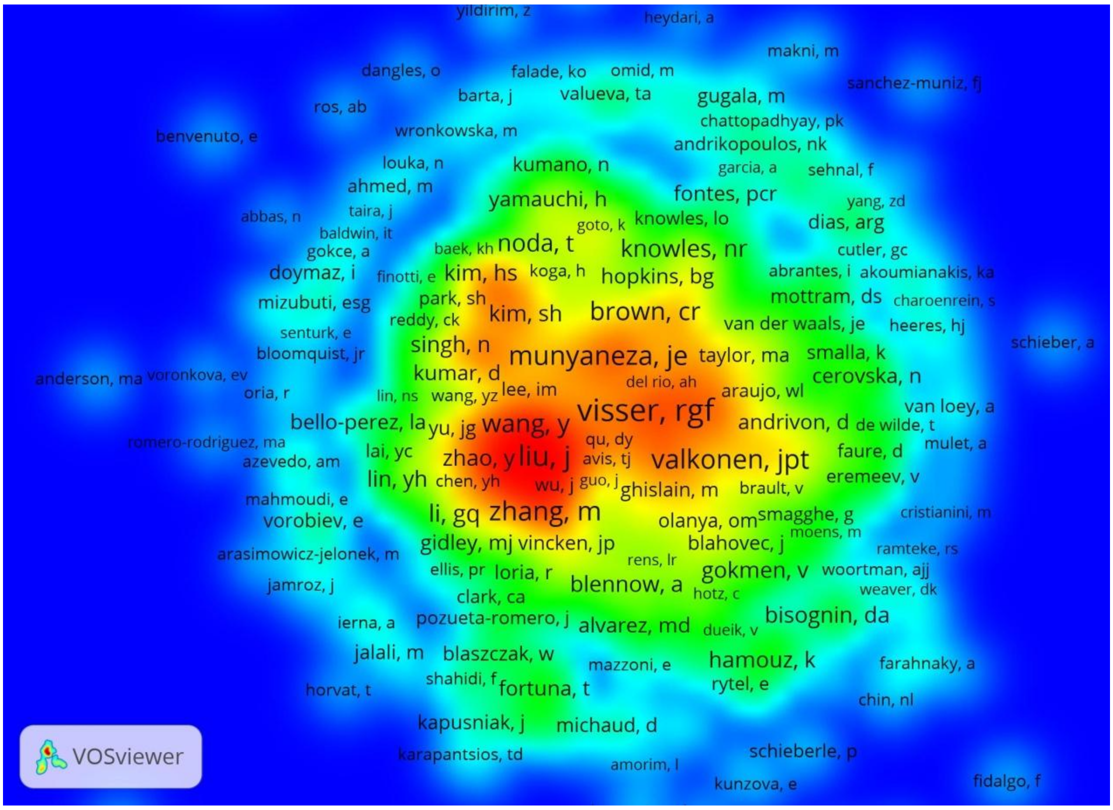

Figure 6 - Map of the collaboration density of the main authors of the analyzed articles. The red color indicates higher density, which means that these words have greater weight or importance; followed by orange, yellow, green and blue colors.

The density of the network is represented by the color variation, from red to green, with a greater or lesser collaboration among the authors. The reddish-colored manuscripts are those with the highest number of connections. Note that the authors already cited are, in fact, the ones that have the most collaboration in the researched area. Thus, in addition to knowing the authors who collaborate and collaborate more, and also their research themes, it is important to know to which institutions the authors belong and also from which countries they are. To do this, Figure 7 presents a map with collaboration by institutions.

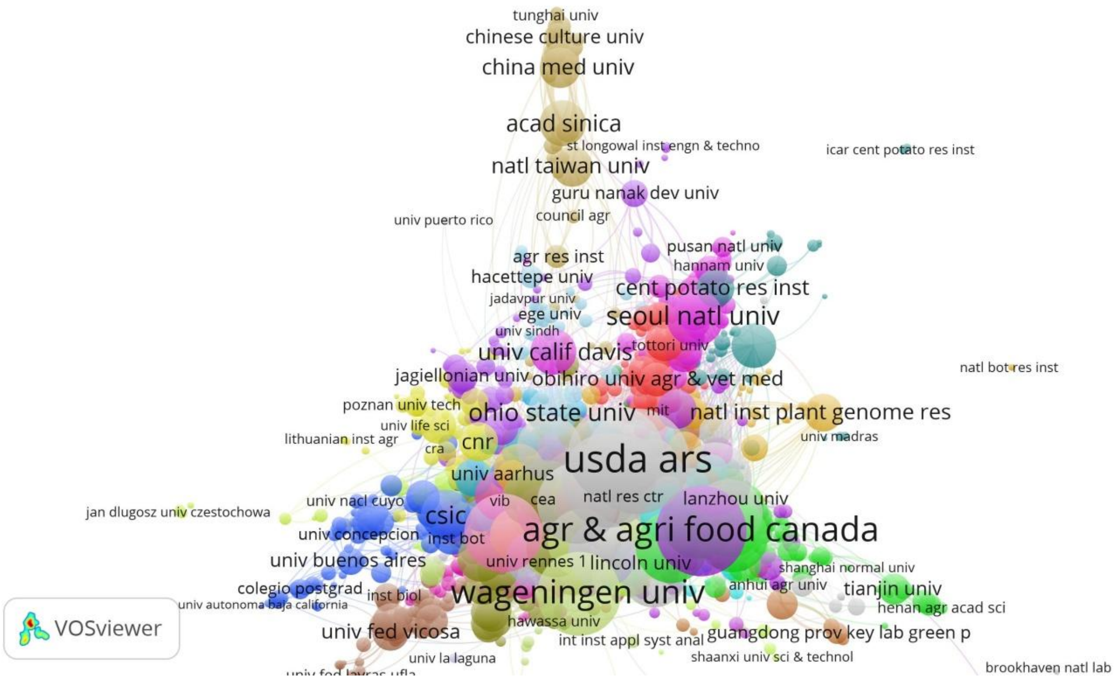

Figure 7 - Map of the collaboration of the main institutions of the analyzed articles.

For the construction of this map, the software identified 9511 institutions throughout all analyzed articles, 1402 of these form the map (those with at least five documents) that is divided into 55 clusters. It is observed that the institution with more collaboration is the Agriculture Research Service (ARS) of the United States Department of Agriculture (USDA). It is responsible for 494 articles published in collaboration with 651 institutions and is located in the gray cluster. Along with it, other institutions such as Cornell University, Washington State University and Wisconsin University also form this cluster, the most collaborative of the entire map. Agriculture and Agri-Food Canada (AAFC) is another collaborative institution that stands out on the map in the purple cluster. It has 400 articles published in co-authoring with 486 other institutions. Along with these, a third cluster attracts attention, the one of dark yellow color, in which is Wageningen University. It appears in 248 publications and counts with the collaboration of 419 institutions in the publication of these articles. The green cluster, although not very prominent on the map, also draws attention to the homogeneity of the circles - located below Agriculture and Agri-Food Canada (AAFC) - which indicates the similar collaboration of the Chinese institutions in the cluster, Chinese Academy of Sciences and China Agricultural University. From Figure 8, it is possible to detail the density of the collaborations of these leading institutions.

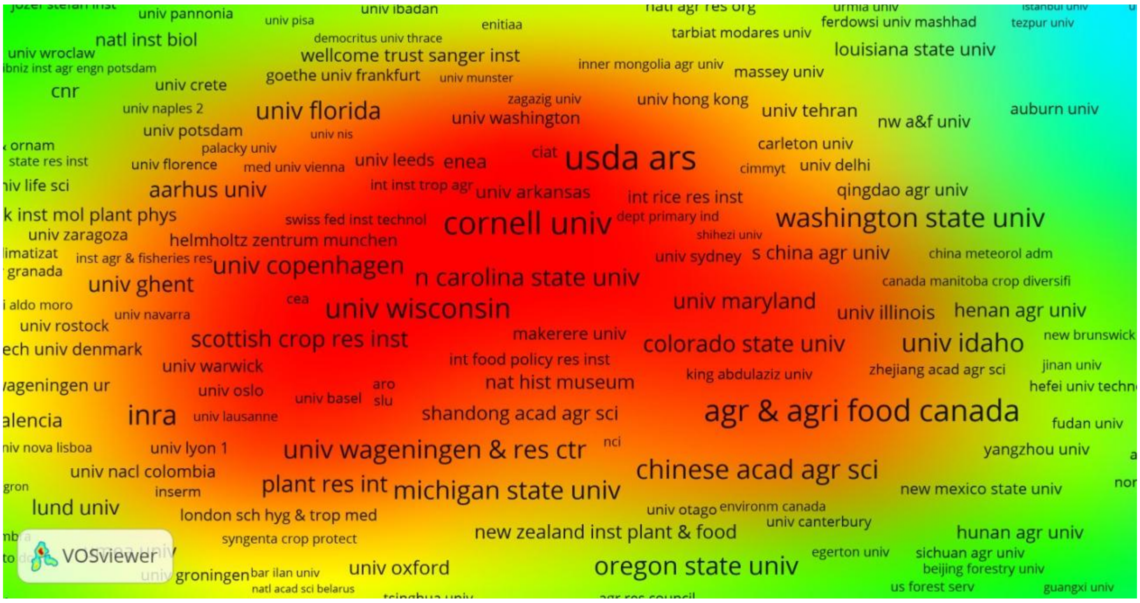

Figure 8 - Map of the density of the collaboration of the main institutions of the analyzed articles. The red color indicates higher density, which means that these words have greater weight or importance; followed by orange, yellow, green and blue colors.

They are located in the red part of the map, that is, the region that has the largest number of connections. In Figure 9 there is the presentation of the map with the countries that most collaborate scientifically.

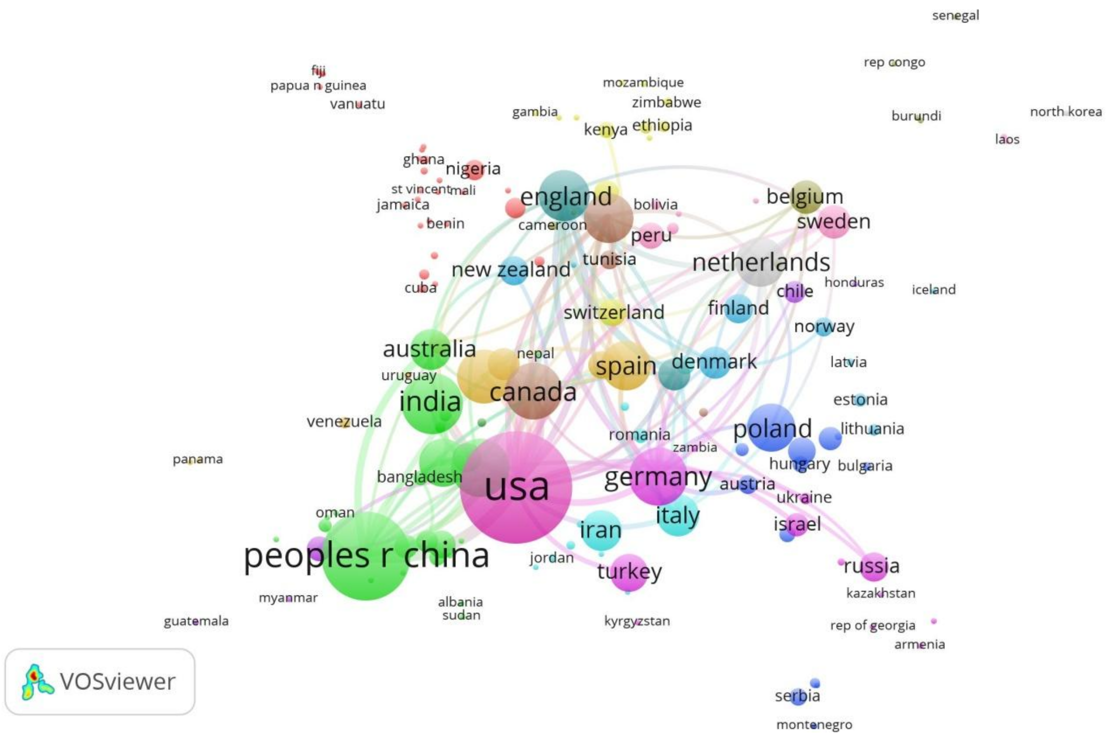

Figure 9 - Map of the collaboration of the main countries of the analyzed articles.

Like the previous ones, the map above was constructed from the co-authoring analysis, in which each country should have at least one document. The software identified 21 different clusters and 1689 connections between each country. The United States and China are the countries that have the most collaboration, although they are in different clusters. Of the analyzed articles, 19% of them, that is to say, 3718 articles have American origin and are responsible for 1934 coauthored papers, being the United States the country that collaborates more in the map. Next comes China, responsible for 2327 articles (12% of the total) and 968 collaborations. These two countries also have the largest mutual collaboration, with 254 connections. Also noteworthy is the collaboration of England and France which, although they are further away from the United States and China and in different clusters, have great importance in international scientific collaboration. Figure 10 shows the density map of these collaborations.

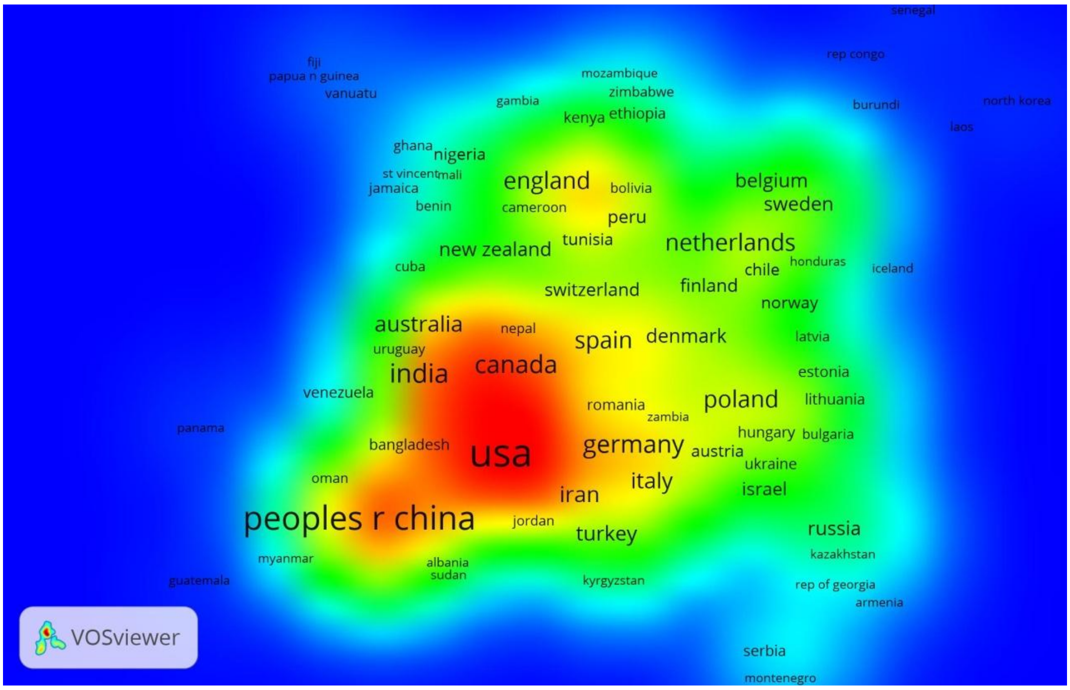

Figure 10 - Map of the density of the collaboration of the main countries of the analyzed articles. The red color indicates higher density, which means that these words have greater weight or importance; followed by orange, yellow, green and blue colors.

Also noteworthy are the contributions made by Canada, India, Germany and Australia to the United States and China. Similar results were found by the latest statistical report published by the US National Science Foundation (NSF). The NSF report studied nearly 2.2 million peer-reviewed articles published in Elsevier's Scopus database, in 2013. Within the European Union, the United Kingdom, France and

Germany had the highest percentages of international collaboration overall. Still according to the report, American authors collaborated most frequently with authors from China, compared with other countries. And scientists from both China and Canada co-authored with American scientists at a higher rate than would be expected from their other international partnerships (Witze, 2016). In Table 1 there is a presentation of the collaborations of the main countries.

Table 1 - Relationship between the main countries and the number of articles and collaborations of each one.

Country	Number of papers	Number of collaboration
United States	3718	1934
China	2327	968
England	764	960
Germany	785	894
France	734	829
Netherlands	711	745
Canada	967	533
Spain	728	528
Italy	525	498
Scotland	315	442
Sweden	335	434
Australia	504	433
Japan	1002	431
Denmark	304	372
Belgium	331	331
Peru	218	305
India	1121	297
South Korea	686	287
Switzerland	236	278
Brazil	868	272

It can be observed in the table that countries with the highest number of publications are not always the ones with the greatest collaborations. Japan, India and Brazil, for example, stand out for the large number of publications each, but are less collaborative than other countries like Canada, Spain and Australia. An effort for greater collaboration between countries could help to address bottlenecks such as the low technological level of India and Brazil and the scarce supply of arable land in Japan. Thus, although China and the United States are the most scientifically productive countries and also the most collaborators, it can be said that this relationship is not always valid for other countries. In addition, it is important to note that, on the map, clusters with more countries do not always indicate those that collaborate more closely. Table 2 lists the clusters identified by the software and the number of countries found in each one of this clusters.

Table 2 - Relationship between clusters and the number of countries in each cluster.

Cluster	**Number of countries**
1 (red color)	28
2 (green color)	23
3 (dark blue color)	14
4 (yellow color)	14
5 (purple color)	12
6 (light blue color)	11
7 (blue color)	9
8 (dark yellow color)	9
9 (dark green color)	8
10 (light pink)	8
11 (color brown)	6
12 (color green-water)	3
13 (pink color)	3
14 (lilac)	3
15	2
16	2
17	2
18	1
19	1
20	1
21	1

According to the cluster map already presented in Figure 8, the United States and China are the countries that collaborate most and are, respectively, in the green and pink clusters. The pink cluster is not the one that has more connected countries, on the contrary, it presents only three countries, nevertheless, the United States is the most collaborative of the entire map. The same thing happens with the red cluster on the map, with 28 countries. Despite the large number of countries in the same cluster, they do not collaborate with each other. This is because there is often collaboration between institutions in the same country and not necessarily with other countries, as appears to be the case with the United States. Something similar is perceived with the European countries, like England and France, that have great collaboration alone or with neighboring countries. Viewed as a bloc, European Union countries lead total global publication output, producing a majority of the articles surveyed. In the case of China, despite belonging to a large cluster and researching similar topics, prioritizes collaborating with the United States.

5. Conclusions

The objective of this work was to measure scientific collaboration in the area of food security through the analysis of articles published in the Web of Science database. The first analysis of the 18,998 articles found, from 1996 to 2006, was that of word co-occurrence. It was carried out in order to identify the themes that appear in the publications and showed that the articles that contained the words "agri*", "food security", "wheat" and "potato" belong to five main scientific fields: 1) genetics, 2) insects and pests, 3) agricultural management, 4) diets and food standards, and 5) chemical characteristics of foods. In addition, genetics (the term "gene") was the subject that predominated in the analysis of the density of terms in the articles, standing out as the main focus of the discussions in the analyzed period. Genetic improvement (and the development of resistant cultivars) has been pointed out as the best way to control diseases in plants - including potatoes and wheat - and can justify the importance of the subject for food security and, consequently, the great occurrence of these terms in the publications.

In the co-authorship analysis, we tried to identify authors, institutions and countries that collaborate scientifically in works on food security. It was again identified that the authors who collaborate most are those who research on biotechnology, genetics, plant reproduction and the development of resistant biotypes. In addition, they are also those authors that have more publications, reaffirming the importance of the theme in the works that involve food security.

In the maps of the institutions, it was verified that the institution that collaborates most is the Agriculture Research Service (ARS) of the United States Department of Agriculture (USDA). It forms the most collaborative cluster and prioritizes its collaboration with other American universities such as Cornell University, Washington State University, and Wisconsin University. When the analysis moves to the level of countries, it can be seen that the United States and China are the countries that have the most collaboration, although they are in different clusters. In the articles analyzed, the United States is the most collaborative country, followed by China. These two countries also have the greatest mutual collaboration, with 254 connections between them. This may be a reflection of the growth of Chinese scientific research and also of the increase in the number of Chinese immigrants in the United States, mostly university students and skilled workers. Furthermore, it reiterates what reports the US National Science Foundation (NSF) studies. Of the nearly 2.2 million peer-reviewed articles analyzed, 412,542 (18.8%) came from the United States, and 401,435 (18.2%) came from China. Moreover, in the period 2003 to 2013, US publications saw an annual average growth of 3.2%, whereas Chinese publications grew 18.9% annually. These are expressive numbers, which show the growth of China's scientific power (Witze, 2016).

In general, the scientific production stored in the databases like Web of Science is an important source of information for the knowledge of a scientific field. As the most used database for evaluating indicators (such as co-occurrence of words and co-authorship), the use of Web of Science in this work was satisfactory. The use of VOSviewer software also met expectations, showing that it is possible to collect scientific indicators from public domain software. It is known that the results presented here do not represent the entire world scientific production on the subject researched, so even though the volume of articles analyzed has been high, they represent only a fraction of the total world scientific production. In addition, as an exploratory research, the terms searched were quite generic, which resulted in articles from different scientific fields related to food security.

Among the possibilities for future studies, the in-depth study for specific scientific fields, such as genetics, is a research topic that can generate results relevant to the evaluation of science. In addition, the methodology could be applied to other databases, especially the patent bank and cultivars. The US National Science Foundation (NSF), for example, this year changed its database. Instead of using the Thomson Reuters Science Citation Index and the Social Science Citation Index, the NSF went with Elsevier's Scopus database. The change was made to try to get a slightly more nuanced view of the world, as well as more information about developing countries (Witze, 2016). Another possibility is the extension of the temporal sample to allow the evaluation of the development of scientific collaboration. The construction of indicators and metrics specific to each specific research area is also important for the evolution of the study. The methods used have already received some criticism regarding the representativeness of the use of words or coauthored to indicate the similarity between documents and the consequent characterization of a research area. Since words can be used with different meanings depending on the context, the study would require a knowledge of the boundaries of a given area prior to performing the analyzes.

Despite the limitations, this work contributes to the understanding of scientific collaboration in the area of food security. Thus, it is relevant for the analyzed period; however, the evaluations must be constant and periodic, since the databases are updated daily.

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CHAPTER 4:
POTATO BREEDING BY MANY HANDS? MEASURING INTERNATIONAL COLLABORATION THROUGH THE GERMPLASM EXCHANGE BETWEEN COUNTRIES.[5]

Abstract

In science, collaboration is sometimes understood as synonymous with co-authorship. However, it can be measured differently. In agriculture, potato late blight is still a challenge to the breeding programs. This article maps the germplasm exchanges carried out by potato breeding in the world to measure collaboration between countries. Cultivars of potato resistant to late blight were selected based on two databases, a European and a Brazilian one. 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. The northern countries, such as Germany and the Netherlands hold most of the resistant cultivars and prioritize the exchange of genetic materials with their own breeding programs. Partnerships with private companies, the acquisition of developed resistant cultivars and technology sharing are approaches that help the increase of genetic diversity and the management of late blight, especially in developing countries.

Resumen

En la ciencia, la colaboración se entiende a veces como sinónimo de co-autoría, aunque puede ser medido de forma diferente. En la agricultura, el tizón tardío todavía ha sido un desafío para los programas de mejoramiento. En este artículo se mapea los intercambios de germoplasma realizadas por el mejoramiento de la papa en el mundo para medir la cooperación entre los países. Se seleccionaron variedades de papa resistentes al tizón tardío en base a dos bases de datos, un europeo y un brasileño. La hegemonía de algunos países, la priorización de las encuestas nacionales, además de los altos costos para desarrollar una variedad resistente puede ser un obstáculo para una mayor colaboración. los países del norte, como Alemania y los Países Bajos, tienen la mayor parte de los cultivares resistentes y priorizar el intercambio de materiales genéticos con sus propios programas de mejoramiento. Las asociaciones con empresas privadas, la adquisición de variedades resistentes ya desarrollados, el intercambio de tecnología son enfoques que ayudan a aumentar la diversidad genética y ayudan a la gestión del tizón tardío, especialmente en los países en desarrollo.

1. Introduction

Collaboration is a growing phenomenon. The earliest studies on the subject date back to the late 1950s, and since then many researchers have studied it (Smith 1958). The word collaboration has a broad concept and, in the case of scientific collaboration, there is still no consensus on how to measure the relationship between researchers. In classical understanding, two people collaborate when they share data, equipment and /

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or ideas in a project, which usually result in publications (Katz and Martin 1997). However, a person can also be considered a contributor by providing materials and assisting in trials (Vanz 2009). Moreover, two countries can collaborate without necessarily involving inter-individual collaboration. Thus, the analysis of co-authorship - widely used in Bibliometrics and Scientometrics - would not be synonymous with collaboration (Katz and Martin 1997). In this way, other measurement tools would be needed. In research for plant breeding, couldn't germplasm exchanges and origin of crosses between cultivars measure collaboration between countries? Believing that it is possible and using potato as object of study of this work, we mapped the germplasm exchanges for the purposes of crosses between countries to measure collaboration between them. Based on two databases, we have selected potato cultivars that are resistant to late blight disease, one of the most devastating diseases in agriculture, and still a challenge to the breeding programs around world.

2. What is collaboration? How can one measure collaborative activity and what does this paper propose?

Collaboration can be defined as working together to achieve the common goal of producing new scientific knowledge (Katz and Martin 1997). Thus, the collaborator may be any individual who gives an input to a part of the research and is responsible for a key step in it. For Latour and Woolgar (1997), scientific collaboration also involves borrowing capital, material or intellectual, in the form of instruments, technique, space and credibility. Moreover, even for Katz and Martin (1997), interinstitutional and international collaboration does not necessarily involve collaboration between individuals. Based on this, the construction of this article is motivated by the question: how could it be possible to measure collaboration between institutions or countries?

Co-authoring analysis articles have been used by many scholars of the Bibliometrics and Scientometrics areas to measure the collaborative activity among researchers. Similarly, the addresses of researchers and institutions in articles have measured collaboration between countries and institutions. The main co-authorship analysis of advantages is the possibility of data verification by other authors and the ease and convenience with which the method allows analysis of large samples, allowing more meaningful results than case studies (Katz and Martin 1997).

Kartz and Martin (1997) point out however, that scientific collaboration doesn't mean co-authorship. The authors of the articles are not always responsible for the work.

In addition, not every collaborative effort among researchers results in publications. Still for the authors, the bibliometric analysis can be compared to precious metals mining. Just like a miner must be careful while selecting the stones and the tools to extract them, scholars can use frequency counts and other statistical tools to explore different publication databases and measure collaboration.

Thus, like a miner, in this work we propose the use of an alternative tool to the publications databases to measure collaboration. We employ here cultivars databases to measure international collaboration on potato genetic improvement. For this we use two databases, a Brazilian one and a European one, which contain information on the potato cultivars maintained by these countries. The exchange of germplasm needed at crossings and held between the countries will serve as a measurement tool of international collaboration in the development of cultivars resistant to late blight.

3. Why is international collaboration important to the genetic improvement of potatoes?

Potatoes are an important staple crop for global food security. It is among the four most produced foods in the world (along with corn, wheat and rice). In addition, it is the food with the most significant increase in per capita consumption in developing countries (Alexandratos and Bruinsma 2012). According to the authors (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). Considering this, it is possible to combine genes of positive effect in the same plant through a genetic recombination obtained by the sexual crossing between different cultivars of the same species. Desirable features are not always available in the same plant. Thus, it is essential to have a gene bank of the species available to define which combinations to make, according to each objective to be achieved. This gene bank is often called germplasm, which are large collections of lineages and cultivars that aim to be donors of their genes for the work of the breeder.

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. This exchange ensures international collaboration and avoids duplication of efforts in breeding programs, as well as optimizes the time to release 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 present below the methodological procedures used to measure international collaboration from potato cultivar databases.

4. Method

This work is based on the analysis of data obtained from two banks of potato cultivars. Data from the European Cultivated Potato Database (ECPD) (https://www.europotato.org/menu.php) and from the Potato Cultivars Catalog of the Brazilian Agricultural Research Corporation - Embrapa - (Embrapa 2015) were used. The first is an online database maintained by eight European Union countries and five Eastern European countries. The second is a publication that presents the main Brazilian potato cultivars released jointly by Embrapa, the Agricultural Research and Rural Extension Company of Santa Catarina (Epagri) and the Agronomic Institute of Paraná

(Iapar). 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. Brazil, on the other hand, is the second largest producer of potatoes in Latin America (only behind Peru), but considered as a promising consumer market for potatoes (FAO 2008).

In both databases, 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 and six cultivars from the Brazilian catalog were used. Information about the country of origin of the cultivar, the countries of origin of the parent cultivars and the holder of the cultivar were also collected.

The databases 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 name of the cultivar, 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 (Ali-Khan et al. 2013; Glänzel et al. 2009). 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.

5. Results

In both databases, 1476 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: the great food industry and economic importance of potatoes for Germany and the Netherlands and the increasing demand of consumers and local legislation for a decrease in the use of agrochemicals 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.

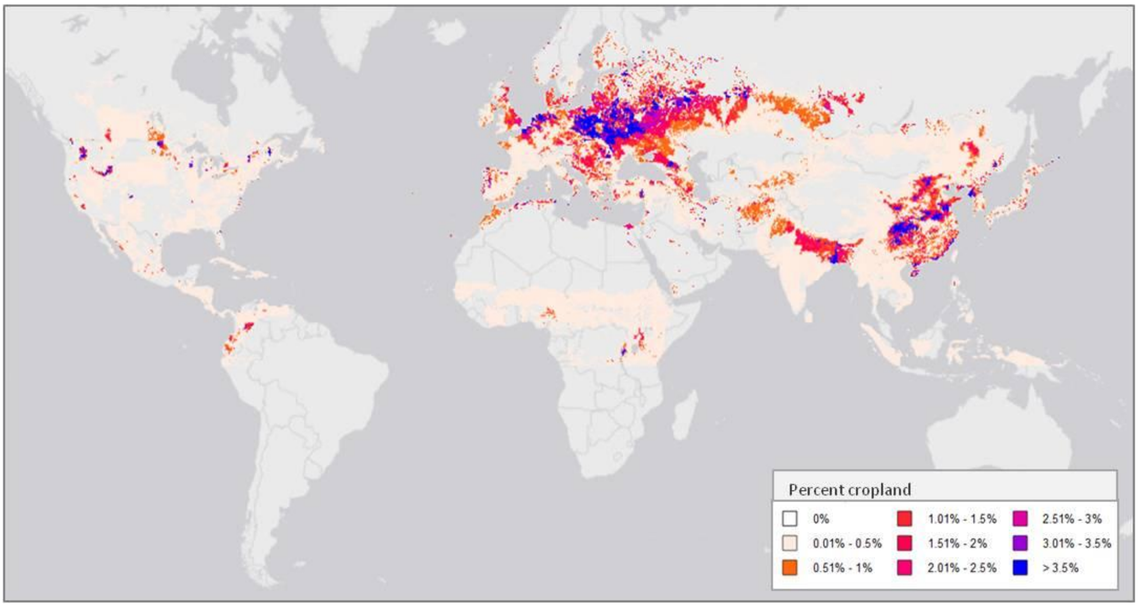

Figure 11 - Geographic distribution of potato cultivation in the world. Source: FAOSTAT (2014).

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$.

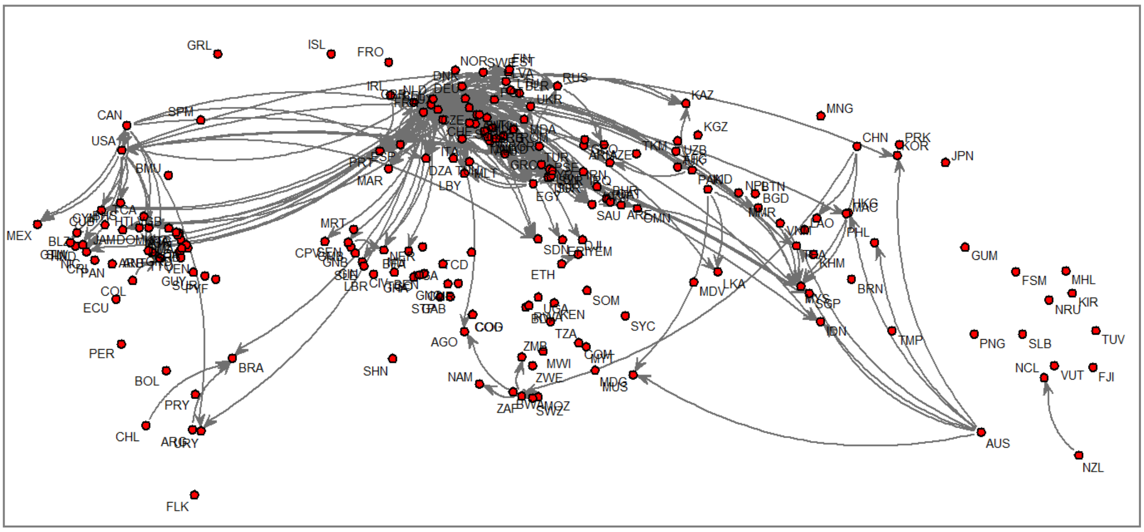

Figure 12 - Trade links of seed potatoes in the world between 2005-2009. Source: Kleinwechter and Suarez (2012).

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 54.5% of all potato cultivars registered as "resistant to late blight" in the databases have medium to high resistance, while 39% 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 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 two databases analyzed, detailed by country of origin and levels of 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	8	5	3	-	-
Byelarus	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	14	10	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
Yugoslavia	2	2	-	-	-
Σ	**1476**	**805**	**581**	**60**	**30**
%	**100%**	**54,5%**	**39,4%**	**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 1476 resistant cultivars recorded in both databases, 506 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. The same happens with Embrapa in the Brazilian bank.

Table 2 - Ten major breeders found in the two databases 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 with ECPD. The following three respond together by 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. There are major breeding programs for cereals, especially corn, wheat and barley, but with potatoes it is not different.

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).

Embrapa is the company that owns five out of the six Brazilian cultivars, two in partnership with Epagri. Embrapa has the oldest potato genetic breeding program in Brazil, maintained uninterrupted since 1946 (Pereira and Costa 2000).

When analyzing the main cultivars used as progenitors of resistant cultivars, Germany and the Netherlands remain ahead of the other countries as parents of their parents. Together, the two countries hold 69.7% of the parents registered in the ECPD. This is because 800 out of the 1470 cultivars identified in this database, that is slightly over 54%, had the countries of origin of their parents. 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	Netherlands
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 wild potato species *(Solanum tuberosum*) that has the R1 gene of *S. demissum* (another 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 Dutch 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 this genetic material, however, seems to have come from South American countries. 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. They were organized mainly to collect germplasm in these countries, which are considered centers of origin of potato (Peru) and *Phytopthora infestans* (Mexico) and would have genetic diversity to be used in crosses that aim for resistance to late blight (Goss et al. 2014).

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 and van Loon 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. 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.

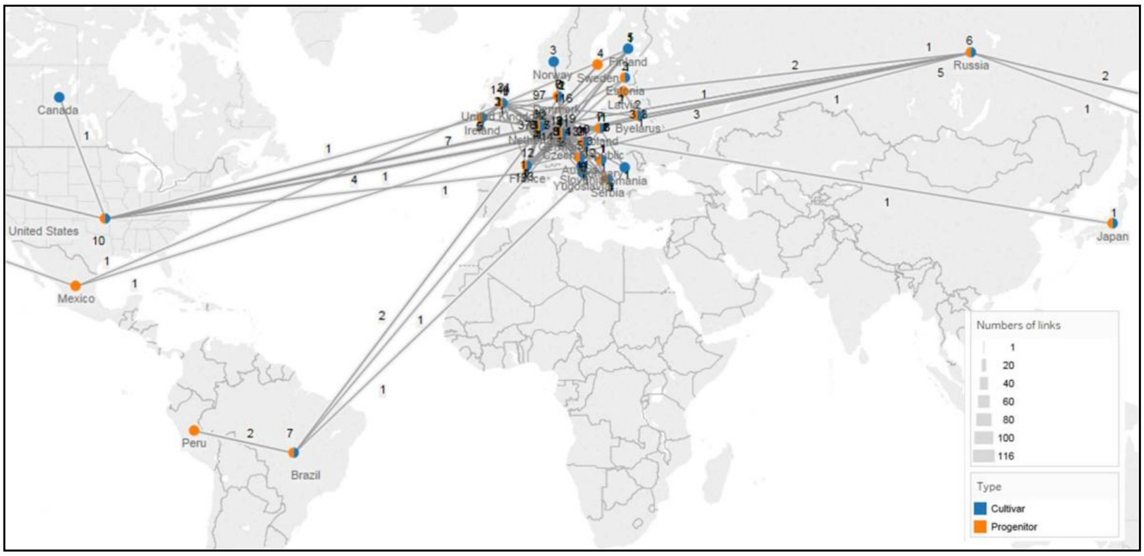

Figure 13 - Map of collaboration between the countries of the cultivars and their parents according to the two databases analyzed.

Comparing this graph with that of the global trade of seed potatoes, it becomes apparent that the links in the two graphs are of 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 the 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, Brazil and Russia, with 10, 7 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. Especially in the case of Brazil, seven out of the country's 13 connections are with itself, that is, its potato cultivars resistant to firewood originate mainly from Brazilian parents.

It is also noted that Peru and Mexico are countries which only provide parents to other countries. This may be justified by the fact that Peru is the center of origin of the potato and Mexico is designated as the possible center of origin of *P. infestans* (Goss et al. 2014). As already explained, both would have genetic diversity to be used in crosses that aim to the resistance to late blight. When analyzing the data standardized by the 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. Most countries have built strong ties with neighboring countries: the link between Brazil and Peru is the strongest, followed by links between Ireland and the United Kingdom, Serbia and the Czech Republic, Russia and Latvia, and France and the Netherlands.

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

Salton's measure for bilateral collaboration amongst the countries																			
	Denmark	France	Germany	Hungary	Japan	Latvia	Mexico	Netherlands	Norway	Peru	Poland	Romania	Russia	Serbia	Slovenia	Sweden	UK	USA	Yugoslavia
Austria			0,049					0,037			0,016								
Brazil			0,009	0,050				0,020		0,365*									
Belarus			0,020			0,068							0,063				0,014		
Canada																		0,030	
C. Republic	0,021		0,055					0,015						0,096*	0,064				
Denmark			0,042					0,013									0,012	0,018	
Estonia			0,008					0,009											
Finland		0,037	0,063					0,014									0,026		
France			0,046					0,077*			0,011		0,011				0,008		
Germany				0,007	0,018		0,013	0,053	0,053		0,030	0,011	0,019	0,035	0,018			0,015	
Ireland								0,041									0,139*		
Latvia													0,078*						
Mexico													0,041				0,028		
Netherlands											0,025		0,004	0,010	0,020	0,022	0,031	0,031	0,028
Poland												0,033					0,016	0,011	
Russia																		0,024	
Slovenia																		0,055	

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

In Figure 4, the links between 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).

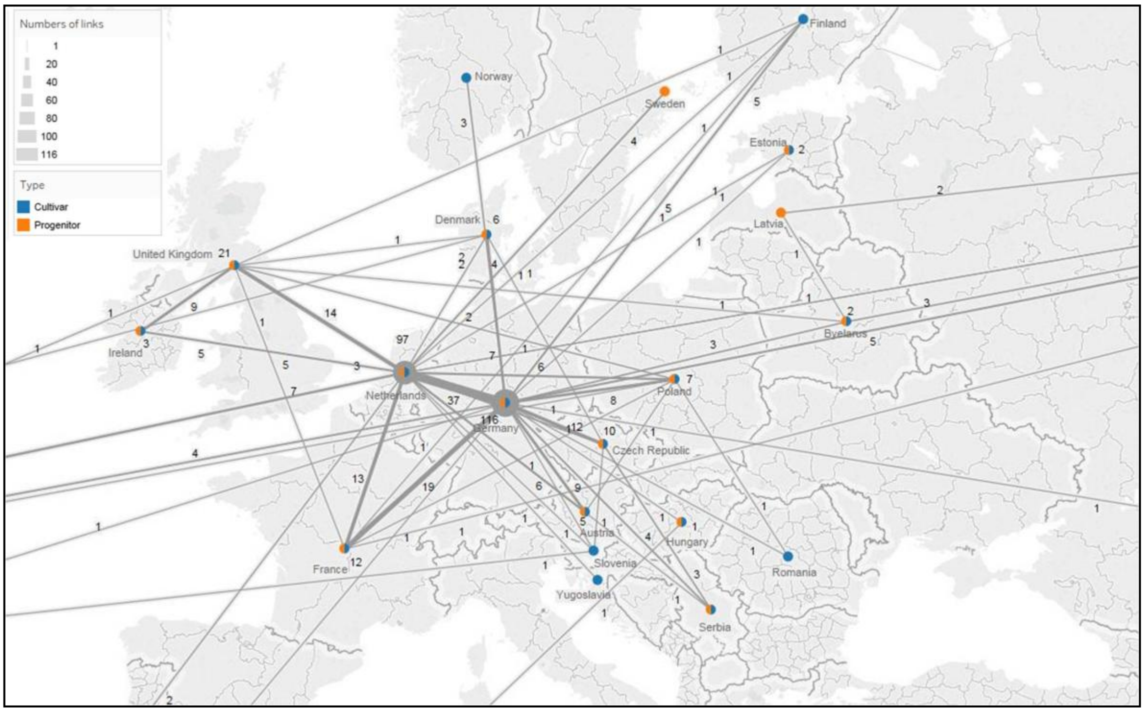

Figure 14 - Collaboration map between the countries of the cultivars and their parents, highlighting the countries of Europe, according to the two databases analyzed.

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 201German 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, this agreement 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 and van Loon 2001).

Another fact that draws attention to the map is that both Sweden and Latvia only provide parents. On the other hand, Finland, Norway, Yugoslavia, 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.

6. 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 2013). This means that the world's potato-producing countries do not research on this staple crop, limiting the consumption and use of the cultivars they produce to the rest of the world, which could pose serious risks to world food security.

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 databases 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 and a Brazilian database were analyzed, some countries stood out from the others. This was mainly the case of Germany and the Netherlands. In the case of Brazil, although one of the analyzed banks is of Brazilian origin, the potato is still cultivated in only a few regions of the country. Yet, as demonstrated by Salton's measure, its link with Peru is the strongest of all other cross-country links. Moreover, compared to European countries that have been researching potatoes for more than 100 years, Brazil is still starting its research on the breeding of this plant (Portal Brasil 2015).

However, 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 with one another 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 potato genetic breeding potato, especially the exchange of germplasm, has been faced by different countries and can help the management of late blight in the future. In addition, 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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CHAPTER 5:
FINAL CONSIDERATIONS

The present thesis is a set of studies related to cooperation, with emphasis in agricultural research. Using wheat and potato as objects of study, the first study characterized the functioning of some agricultural research networks and aimed to highlight the benefits of networking in agricultural research networks that manage diseases in wheat and potato crops. The second article measured scientific collaboration in wheat and potato publications through co-authorship analysis. Finally, the third article mapped the germplasm exchanges conducted by potato breeding programs in the world.

Thus, considering the worldwide importance of food security efforts and the examples of collaborative actions that illustrate this thesis, especially in the first article, it can be seen that scientific collaboration in agricultural research has more benefits for disease management than the isolated research. The first of these benefits is resource savings, reduced duplication of efforts and research, and faster scientific advances. A second one is the contribution of collaborative research to the reduction of existing technology divide between the northern and southern hemispheres of the world and the guarantee of developing countries access to advanced technologies, particularly those in Africa, Asia and South America. A third benefit is the guarantee of continuity in agricultural development of countries and the sharing of information and research ideas between countries and institutions. A fourth one is that these global collaborative efforts can serve as anticipatory actions as they monitor the evolution of pathogen populations and can identify and exchange sources of resistance around the world. Thus, for developing countries, collaboration can mean more resources to be invested in agricultural research; to developed countries, can provide greater genetic diversity.

The results of the second article indicate the potential of plant breeding in disease management and to guarantee food security. In the 20-year period (1996-2016), the term "gene" predominated in the analysis of the density of terms in the articles published in the Web of Science. Among the authors who most collaborate, the study pointed out that there are also those who research biotechnology, genetics, plant reproduction and the development of resistant cultivars. Among the countries, the United States and China are the most collaborative. This demonstrates the growth of China's scientific power and its concern about the need to feed a country that has almost a fifth of the world's population.

In the third article, the importance of plant breeding was exemplified in germplasm banks and materials exchanges held between potato breeding programs around the world. The results showed that Peru, as the birthplace of potatoes, and Mexico, the origin center of

Phytopthora infestans, potentially have more genetic diversity of materials and have therefore been the targets of numerous international expeditions to collect materials. Germany and the Netherlands made numerous expeditions to these places and may have benefited from these informal exchanges. Similarly, in formal trade, Germany and the Netherlands proved to be the largest holders of late blight-resistant genetic material. Both also had the largest number of mutual collaborations, while Brazil and Peru had the strongest link. However, India and China, the world's potato-producing countries, do not research on this staple crop. This could pose serious risks to world food security, since this limits the consumption and use of the cultivars they produce to the rest of the world.

In general, the three studies in this thesis corroborate the importance of cooperation - scientific collaboration - and the potential of plant breeding in plant disease mitigation. Thus, both agricultural research networks, as scientific publications and germplasm exchanges are pro-food security actions necessaries for the advancement of science and the sharing of information, knowledge and genetic materials resistant to potato late blight and wheat rust.

This study has some limitations, such as the choice only of wheat and potatoes as objects of study. Other globally important crops such as rice, maize and cassava would also deserve attention. However, these studies were based on data obtained from public institutions and organizations, and the unavailability of information on these other foods restricted some analyzes and made certain inferences impossible. Another limitation was found with respect to the use of software for the construction of collaboration maps. Many of the free software tested and indicated for network analysis (QDAMiner, SimStat, VOSViewer and ORA) do not allow the entry of duplicate data, as in the case of countries holding both progenitors and cultivars resistant to potato late blight. Through these softwares could be calculated indices of density, centrality, intermediation, power, prestige, cohesion, among others, and analyzed according to the theoretical field that characterizes each of them. Therefore, it was decided not to use network analysis and to use Tableau software for the construction of geographic and non-clustered maps. In addition, another important limitation is the construction of articles based on bibliographic data and bibliometric and / or quantitative indicators.

Thus, as suggestions for future studies, the use of qualitative indicators such as questionnaires and interviews with members of collaborative networks could be contemplated to complement the studies. In addition, collaborative analyzes could be extended to other countries, crops and institutions. Identifying patterns of collaboration over time and studying the evolution/decline of science fields would also be relevant and necessary studies. Different germplasm banks or patent banks are also shown as possible sources of information for collaborative measurement and could be used in other studies. Likewise, additional studies that seek to analyze cooperative relations within a single country or bilateral agreement are also relevant. Finally, additional studies that seek other metrics to measure scientific collaboration and also that aim to understand why stakeholders cooperate are strongly encouraged.

In general, despite its limitations, this thesis aimed to study collaborative relations in agricultural research. Thus, its results allow for broader reflections than those already presented in the three articles and instigate new research questions. The first of these reflections concerns the role played by each country in the collaborative networks and the real intention of the developed countries collaborations with the developing countries. What are the gains for developing countries? Are these gains greater for developed or developing countries? A second reflection is on the motivations for collaborations. Are these collaborations based on a concern for world food security or are they only economically concerned about holding resistant cultivars and patents? So, are these collaborative actions altruistic or looking for a future reward? Why does China choose to collaborate scientifically with the United States in publications? What does the United States gain from this? And in the case of European countries, why the preference for collaboration between them? What is the counterpart to Peru and Mexico, for example, as a source of potato genetic diversity?

Finally, what causes private companies and donors to fund collaborative research? Being optimistic, could we think that these collaborations seek to reconcile the public interest with the financial return? Is collaborative investment an immediate financial sacrifice required for the network to fulfill its social purpose and endure in the long run?

All of these questions are difficult to answer and the intentions of collaborators are also difficult to measure. Even if interviews and surveys were carried out, perhaps not all of these questions would be elucidated, given the great number of motivations that make people cooperate. In any case, this study is expected to contribute to the identification of "who collaborates with whom" in solving challenges that can not be solved individually, such as disease management and perhaps, food insecurity. This thesis is the result of a multidisciplinary effort, which aimed to understand the theme of cooperation by different areas of knowledge, such as bibliometrics, agribusiness, phytopathology and plant breeding. In this way, it contributes to the understanding of cooperation as a fundamental approach to the mitigation of plant diseases and the risks of global food insecurity.

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