



Prevalence of airborne fungal spores in two potato warehouses with different storage conditions

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Abstract Potatoes production is the main source of income in A Limia (Northwest Spain). Most of the potatoes harvest is stored in piles in farmer's warehouses without systems to control temperature and relative humidity and only a few industries have storage facilities with cooling systems. This study constitutes an approach to detecting fungal spores present inside potato warehouses and the influence of the environmental conditions on the prevalence of the different types of fungi. The most common spores were *Cladosporium* and *Aspergillus/Penicillium* representing more than 94% of the identified spores of fungi. However, some potential fungal potato pathogens such as *Alternaria*, *Helminthosporium*, *Fusarium* and *Phytophthora* were also detected. In the warehouse without control of the storage conditions, the most represented fungal spores were from *Cladosporium* followed by *Aspergillus/Penicillium*, *Helminthosporium* and *Alternaria* whereas during storage with cooling conditions, the most abundant were *Aspergillus/Penicillium*, *Cladosporium*, *Fusarium*, *Helminthosporium* and *Leptosphaeria*. The results showed a close relationship between the storage conditions and the levels of some identified

fungi. The low representation of pathogenic fungi *Alternaria* and *Helminthosporium* stood out in the facilities with cooling systems. Monitoring of airborne elements during potato storage could be useful tool for detecting the presence of potato pathogens in the environment and taking management decisions to avoid economic losses.

Keywords Potatoes · Storage conditions · Aerobiology · Fungal disease

1 Introduction

Potatoes are the third most important crop in the world, after rice and wheat, with a total production that exceeds 300 million tons (CIPOTATO 2019). In the late 1500s, the potato crops were dispersed from Peru to Europe and over the next two centuries exported to North America, Australia, and China, and then elsewhere (Pringle et al. 2009). One of the reasons for the quick expansion was the nutritional value of the potatoes as they provide an excellent source of nutrients and vitamins. However, year-round availability depends on harvest and industrial-scale storage, especially in countries that rely on an annual crop (Alamar et al. 2017).

In some areas of Europe, the potato crop constitutes the main source of incomes for the population.

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However, the area of production of the potato crop in the European Union crop has reduced by 30% since the year 2000. This downward trend is caused mainly by the presence of common pathologies such as fungal or bacterial diseases and insects that cause significant losses and reduce the benefits for farmers. Besides, suboptimal handling, poor tuber quality, and deficient postharvest storage can lead to significant amounts of waste and economic loss (Alamar et al. 2017). The high quality of tubers is fundamental, demanded firstly by consumers for their daily fresh diet, and secondly by the industry, which requires healthy tubers for the mechanical processing of potatoes (Hofmann 2009).

Potato production constitutes the most traditional agricultural activity in A Limia (Northwest of Spain) and represents together with the cereal crops, alternating in rotation, the main economic activity for families. More than 6000 ha of tubers are planted each year, producing nearly 190,000 t of potatoes (MAPA 2019). Some of the varieties intensively cultivated are Kennebec, Agria and to a lesser extent Frissia, Monalisa, Fontane and Dayfla. The Kennebec potato tubers are covered by the label Protected Geographical Indication “Patata de Galicia” recognized in the European Union since 2007 (Commission Regulation EC No 148/2007).

Despite the importance of this crop in A Limia, storage systems are poorly developed. Only a few companies have technical facilities in which the storage conditions of the tubers can be controlled. Generally, farmers store tubers in large piles inside warehouses without control of the environmental conditions. In this situation, the spreading of pathogens and the development of diseases are common during the storage period. Among the common diseases, fungal diseases caused by *Alternaria*, *Fusarium*, *Helminthosporium*, *Pythium* or even *Phytophthora* are highlighted (Atallah and Stevenson 2006; Escuredo et al. 2007; Hofmann 2009). Nevertheless, some potato-trading companies store potatoes in local storage facilities with cooling systems. These systems allow environmental conditions to be controlled, adjusting desirable temperature and humidity intervals, so significant fluctuations in these parameters do not occur. Potatoes are mainly stored in wooden boxes. These boxes allow air circulation improving stored conditions but they can also serve as growth medium to some fungi present in the air of facilities. The strategies to control the evolution of these

diseases are based on prophylactic measures such as the elimination of damaged tubers. However, the storage procedure does not allow the easy and quick identification of deteriorated tubers. Consequently, the disease progresses and causes tuber decay and the deterioration of the quality of large quantities of potatoes along with the reduction of shelf life.

Aerobiology constitutes a useful and valid tool for identifying the levels of biological agents such as pollen grains and fungal spores in the environment. Studies on fungal elements mainly focus on the fungi that affect human health both in outdoor and indoor environments (Crawford et al. 2015; Gomez de Ana et al. 2006; Kim et al. 2018; Portnoy et al. 2005). However, there are few bibliographical references on the use of these detection systems to study the presence of fungi with potential pathogenicity risk in agricultural warehouses such as potato storage facilities. Nevertheless, considering the airborne behaviour of fungal spores, this discipline can be useful for assessing the presence of fungal diseases in agricultural crops and their warehouses (Escuredo et al. 2007, 2011; Fernández-González et al. 2013; Iglesias et al. 2010; Martínez-Bracero et al. 2019; Meno et al. 2019; Rodríguez-Rajo et al. 2010; Seijo-Rodríguez et al. 2018). Therefore, this work presents the results of the air monitoring of two potato warehouses during the storage period of the tubers. The objective was to compare two different storage environments and provide a method for the early identification of the presence of pathogens in the environment of stored potatoes that allows farmers and companies to make short-term decisions.

2 Materials and methods

2.1 Storage conditions and period of study

The present study was carried out in two potato warehouses located in A Limia (Northwest Spain) during two postharvest seasons. The first storage period was from October 28, 2017 to January 6, 2018 and the second was from November 15, 2018 to January 25, 2019.

The warehouses were situated at 4 km distance. One of them is a common farmer warehouse, being a scarcely conditioned building in which around 450 t of potato tubers were stored in a pile of about a 4.5 m

high. The storage conditions (temperature and relative humidity) were strongly influenced by the outdoor weather since there was no technology to control environmental parameters. This system was called an ambient air system. The second emplacement was a potato trading company warehouse. The tubers were stored in half-ton wooden boxes inside a conditioned warehouse. The boxes allowed air circulation through potatoes and temperature and relative humidity were under control. This system was called cooling system and can maintain temperature at a small range, between 6.5 and 7.5 °C without high fluctuations during the entire postharvest period.

In both warehouses indoor temperature and relative humidity were recorded with a Hobo Pro series HO8-032-08 automatic recorder, which provides hour-by-hour data. The recorder was located in the same place as the spores sampler.

2.2 Aerobiological monitoring method

The methodology proposed by the Spanish Aerobiological Network was performed for the air monitoring, sample preparation and the counts of the fungal spores (Galán et al. 2007). A volumetric collector of the Hirst desing model Lanzoni VPPS 2000 located inside the storage area was used to monitor the presence of aerobiological particles per cubic meter of air. This device has a weekly changed drum, that is covered with a Melinex tape impregnated with a 2% silicone solution. The device has a pump to suck the air of the environment so the particles and biotic elements impact on the Melinex tape and stick to that. Each week the tape was replaced by another and was cut into daily fragments to prepare the slide for the microscopical analysis. Using an Optiphot Nikon II microscope, the spores were identified and quantified. The magnification used was 400 × or 1000 ×, according to necessity. The different fungi elements (spores and conidia) were identified using reference slides of fungal spores and different manuals (Grant-Smith 2000; Leilslie and Summerell 2006). The obtained data were expressed such as spores/m³ when referred to daily data and total number of spores when referred to the accumulated values.

2.3 Data processing and statistical analysis

Data were processed and statistically analysed using the software package STATGRAPHICS Centurion XVII and IBM SPSS statistics version 25. Spearman's linear correlation test was used to study relationships between environmental factors and the daily airborne concentration of spores. Also, relationship between the levels of spores in a given day and the levels in the 3 previous days was studied. All relationships with *p*-value < 0.05 were considered statistically significant. Canonical correlation analysis (CCA) was used to find associations between the different spores identified in each warehouse and the environmental conditions of storage.

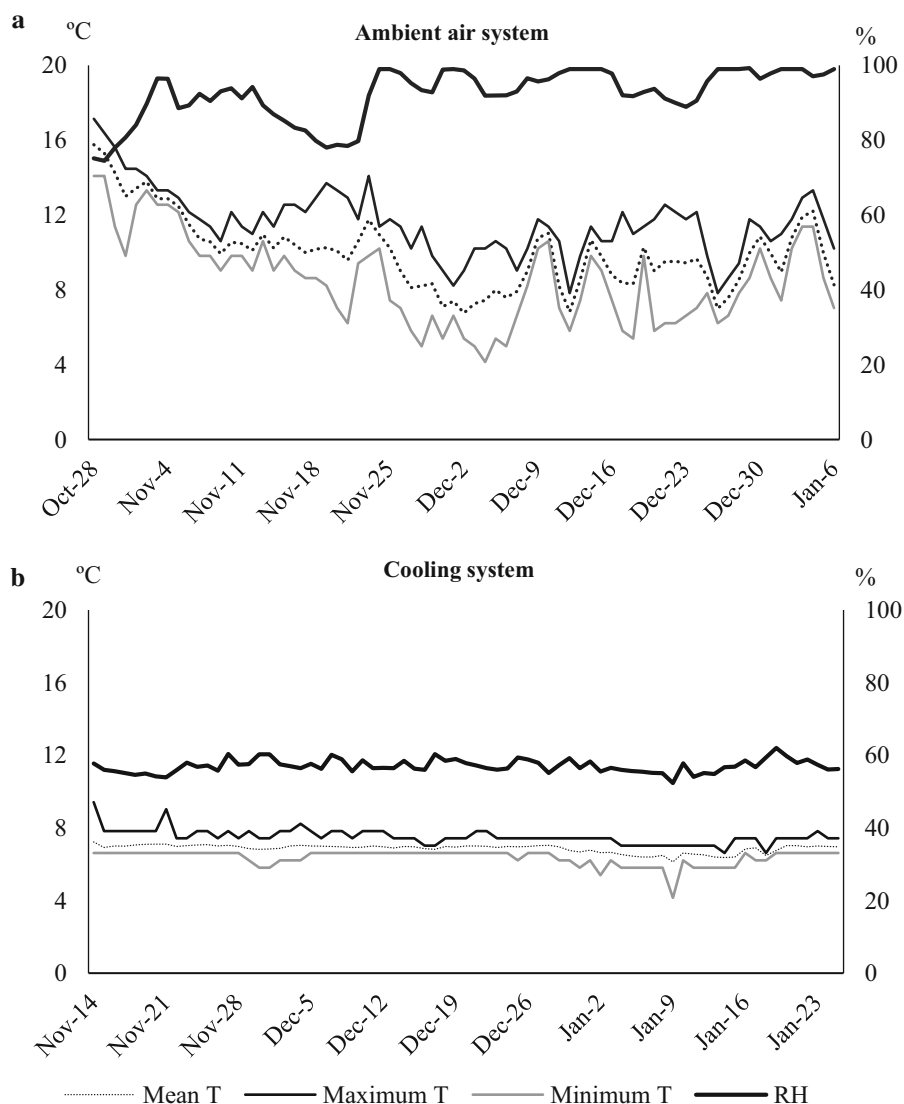
3 Results

3.1 Environmental conditions in both systems during the storage

Potatoes were stored for 71 in the first postharvest season and 73 days in the second postharvest season of study. This was in two different warehouses, one with ambient air system and the other with cooling system (Fig. 1). There were important changes in temperature during the storage time in the warehouse without the control of environment (Fig. 1a). The lowest mean daily temperatures (7 °C) were recorded in December, coinciding with the 39th, 49th and 63rd days of storage while the highest temperatures were registered on the 2nd, 3rd and 4th days of storage in which the average daily temperatures were about 15.5 °C. On the contrary, temperature and relative humidity were constant throughout the storage period in the warehouse equipped with the cooling system. Minimum daily temperature was 4.1 °C registered on the 57th day of storage and maximum daily temperature was 9.4 °C in the first day of the study. Mean daily temperature was between 6.1 and 7.2 °C for the entire storage period (Fig. 1b).

The mean daily relative humidity in the ambient air system was 91.7% and the value was frequently 100%. Only during the first days of storage, the relative humidity was below 75% (Fig. 1a). The environment of the warehouse with the cooling system was dryer, being 57% the daily mean of relative humidity

Fig. 1 Daily temperature (mean, maximum and minimum) and mean relative humidity during the tuber storage in two storage systems: Ambient air system (a) and cooling system (b)



(Fig. 1b). Maximum and minimum values were 62% and 52%, respectively.

3.2 Spores in the environment of both warehouses: ambient air system and cooling system

In the ambient air system 24,715 different types of spores of fungi were counted during the period (Table 1). The best-represented fungi in the atmosphere were *Cladosporium* with 70.4% of the total quantified fungi and *Aspergillus/Penicillium* with 23.9%. Other common potato pathogenic fungi stood out and comprised 4.3% of all detected fungi, these

being *Helminthosporium*, *Alternaria*, *Fusarium*, and *Phytophthora*. Other fungi present in low concentrations were *Leptosphaeria*, *Stemphylium*, *Pleospora*, *Agrocybe*, *Drechslera*, *Puccinia* or *Fusichalara*. The presence of fungal spores of *Curvularia*, *Amphisphaeria*, *Fusicladium*, *Cerebella* or *Sporidesmium* was unusual.

In the cooling system warehouse, a total of 66,414 different types of spores of fungi were counted. The most represented fungi were the group *Aspergillus/Penicillium* with 96.3% of the total fungal spores, while *Cladosporium* represented only the 2.9% of total. This warehouse presented a small quantity of spores from potato pathogens, being 0.5% of total

Table 1 Main identified fungal spores in the environment of two storage systems, their relative frequency and maximum concentration

	Ambient air system			Cooling system		
	Spores	%	Maximum value (spores/m ³)	Spores	%	Maximum value (spores/m ³)
<i>Agrocybe</i>	29	0.1	14	–	–	–
<i>Alternaria</i>	430	1.7	50	41	0.1	9
<i>Aspergillus/Penicillium</i>	5911	23.9	438	63,988	96.3	1937
<i>Botrytis</i>	–	–	–	66	0.1	8
<i>Cladosporium</i>	17,412	70.4	1669	1913	2.9	356
<i>Fusarium</i>	179	0.7	19	172	0.3	12
<i>Helminthosporium</i>	465	1.9	69	97	0.1	9
<i>Leptosphaeria</i>	108	0.4	8	96	0.1	10
<i>Phytophthora</i>	10	0.0	2	11	0.0	2
<i>Pleospora</i>	43	0.2	4	–	–	–
<i>Stemphylium</i>	45	0.2	5	1	0	1
Other *	29	0.5	4	11	0.1	3
Total identified spores	24,725	100		66,425	100	

*Other: fungal elements found with a percentage lower than 0.5%

identified spores. The most abundant pathogen was *Fusarium* followed by *Helminthosporium*, *Alternaria* and *Phytophthora*. Other spores of *Leptosphaeria*, *Botrytis*, *Paraphaeosphaeria*, *Phaeosphaeria*, *Amphysphaeria*, *Curvularia* and *Stemphylium* were obtained in very small quantities.

In the ambient air system, the concentration of the spores measured as spores/m³ varied according to time of storage, whereas in the cooling system the spores concentration had a lesser variation throughout the storage period (Fig. 2). In both cases movements inside the warehouse caused an increase in the indoor spores level. This was especially relevant in the ambient air system where the potatoes were selected for market, approximately one month and a half since the storage started. The highest increment happened in the last week of storage when the commercialization of the tubers started.

The different types of spores of *Alternaria*, *Helminthosporium*, *Phytophthora* and *Fusarium*, all of them common fungal pathogens in stored potatoes, were found in all the stages. Concerning the *Alternaria* concentration, maximum values were recorded in the ambient air system (50 conidia/m³), whereas the highest values in the cooling system were 9 conidia/m³ (Table 1). The same occurred for *Helminthosporium* conidia, as the maximum values were 69 conidia/

m³ per day in the ambient air system and only 9 conidia/m³ in the environment of the cooling system. However, *Fusarium* presented a similar maximum value in both systems, 19 conidia/m³ for the ambient air system and 12 conidia/m³ for the cooling system. Finally, the concentrations of *Phytophthora* were low in both stored systems with maximum daily values of 2 sporangia/m³. Other non-pathogenic fungi of potato tubers as *Aspergillus/Penicillium* or *Cladosporium* were found in both systems (Fig. 2). Stood out the highest values for *Penicillium/Aspergillus* in the cooling system in front of the most abundant values of *Cladosporium* in the ambient air warehouse.

The relationships between the main spores and the environmental parameters recorded in the warehouse were analysed through a Spearman rank correlation analysis (Table 2). For this purpose, daily temperature (mean, maximum and minimum) and mean relative humidity of the day for the previous 3 days were considered. Significant positive correlation coefficients ($p < 0.01$) were found between temperature (mean, maximum and minimum) and relative humidity in *Alternaria*, *Helminthosporium* and *Cladosporium* levels. *Fusarium* only had the significant correlation coefficient with minimum temperature of the same day and up to two days before ($p < 0.01$) and mean temperature of one day before ($p < 0.05$). The

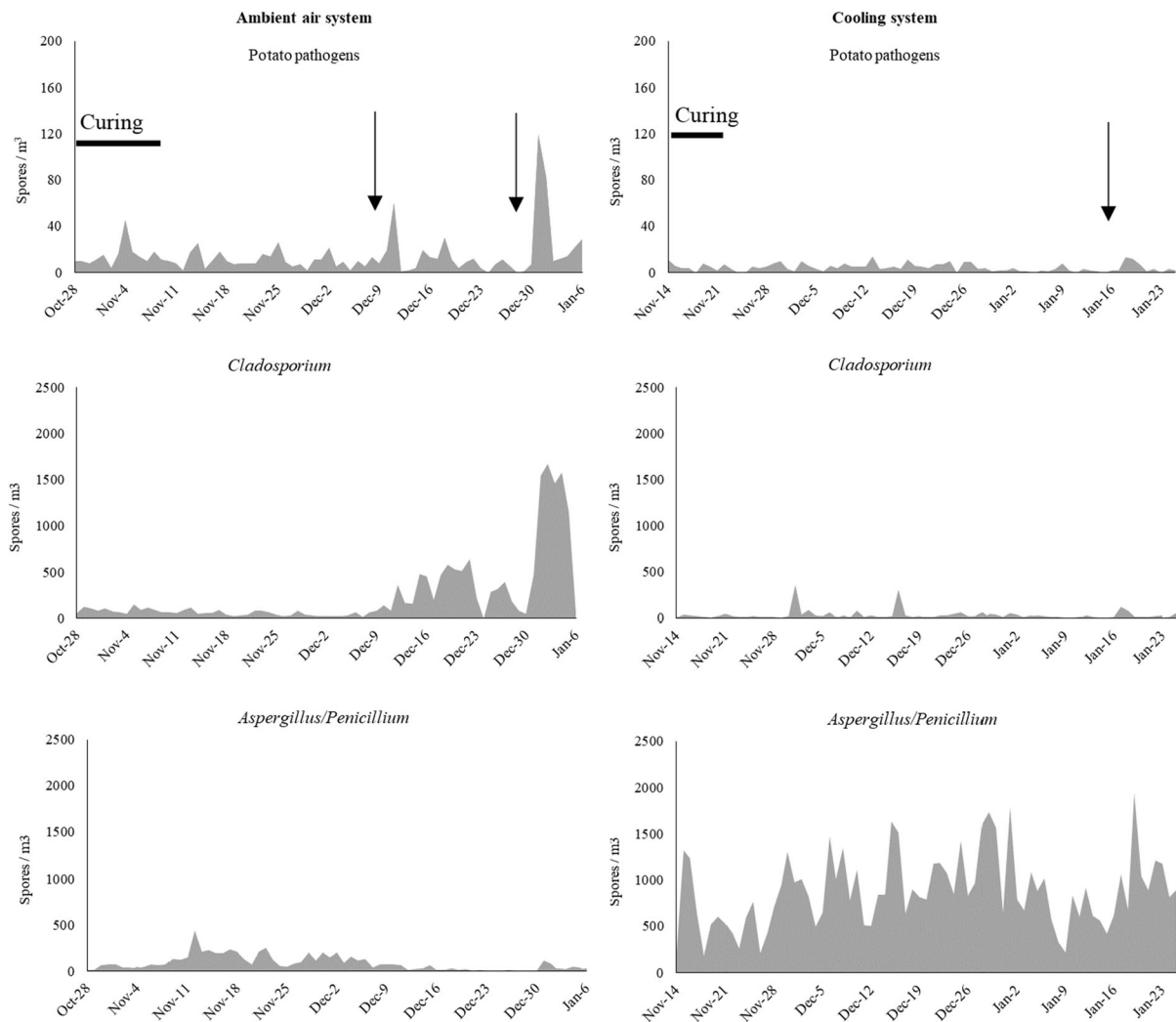


Fig. 2 Distribution of the main fungal spores inside the warehouses during the storage period. Arrows show main tubers movements in warehouses

negative correlation coefficient ($p < 0.01$) between temperature and relative humidity over the previous three days and the spores of *Aspergillus/Penicillium* ($p < 0.05$) is highlighted.

To deepen in the associations between the different spores counted in each environment and the stored conditions, a canonical correlation analysis was applied. The analysis used two set of variables, one was the main fungal spores identified and the other the storage conditions. The first two canonical correlations obtained were statistically significant ($p < 0.05$). The highest canonical correlation coefficient had a value of 0.83 and the second one a value of 0.38 (Table 3). The variable with the greatest weight in set

one was *Aspergillus/Penicillium* whereas in the second set, mean daily relative humidity and the maximum daily temperature were those with biggest weight. As can be seen in Fig. 3, the plot of both canonical variables showed two groups of cases corresponding to the observations in the ambient air system (a) and the cooling system (b).

4 Discussion

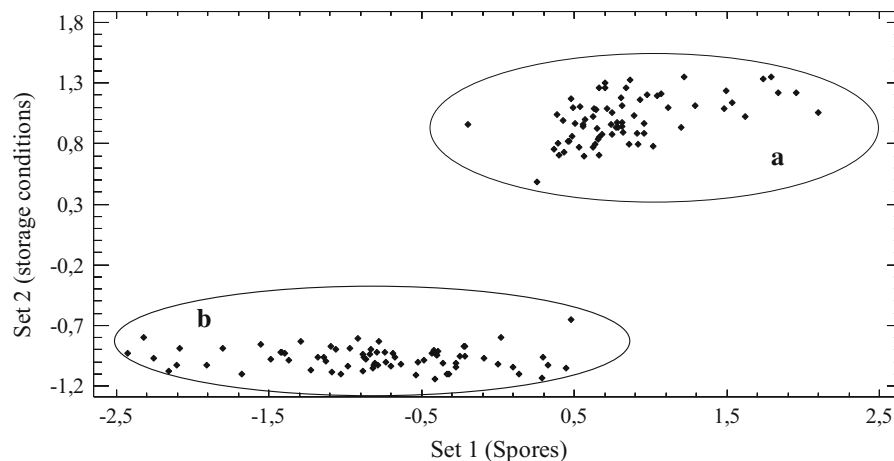
The presence of fungal spores in indoor buildings is well known due to its consequences for human health (Crawford et al. 2015; Kim et al. 2018; Portnoy et al.

Table 2 Spearman correlation coefficients between the temperature, the relative humidity and the main fungal spores up to 3 days before

	<i>Helminthosporium</i>	<i>Alternaria</i>	<i>Cladosporium</i>	<i>Fusarium</i>	<i>Aspergillus/penicillium</i>
Mean temperature	0.412**	0.578**	0.598**	0.153	− 0.703**
Day-1	0.450**	0.649**	0.600**	0.173*	− 0.691**
Day-2	0.456**	0.635**	0.601**	0.144	− 0.688**
Day-3	0.445**	0.619**	0.585**	0.076	− 0.683**
Maximum temperature	0.423**	0.617**	0.619**	0.078	− 0.734**
Day-1	0.455**	0.633**	0.620**	0.114	− 0.744**
Day-2	0.447**	0.654**	0.634**	0.093	− 0.740**
Day-3	0.435**	0.618**	0.605**	0.075	− 0.721**
Minimum temperature	0.310**	0.303**	0.388**	0.293**	− 0.399**
Day-1	0.328**	0.426**	0.415**	0.320**	− 0.381**
Day-2	0.396**	0.416**	0.418**	0.238**	− 0.385**
Day-3	0.375**	0.406**	0.432**	0.115	− 0.367**
Mean relative humidity	0.363**	0.553**	0.651**	0.047	− 0.741**
Day-1	0.380**	0.518**	0.647**	0.037	− 0.736**
Day-2	0.342**	0.536**	0.678**	0.057	− 0.718**
Day-3	0.315**	0.581**	0.713**	0.040	− 0.713**

** $p < 0.01$; * $p < 0.05$ **Table 3** Canonical correlations obtained

Number	Eigenvalue	Canonical correlation	Wilks lambda	Chi-square	p
1	0.69	0.83	0.258	186.72	0.00
2	0.14	0.38	0.845	23.08	0.01
3	0.01	0.10	0.989	1.49	0.83

**Fig. 3** Plot of the canonical variables. Ambient air system (a) and cooling system (b)

2005; Wirmann et al. 2018). The best represented fungi in the atmosphere of the two warehouse systems

were from cosmopolitan genera such as *Aspergillus/ Penicillium* and *Cladosporium*, the most common

fungal spores in outdoor and indoor environments (Aira et al. 2012; Grinn-Gofroń et al. 2019; Sindt et al. 2016).

High quantities of *Aspergillus/Penicillium* during all the stored period were identified in the cooling system warehouse when comparing with the ambient air system, differentiating both environments. *Penicillium* is the most prevalent airborne mold type in all regions being common in damp materials in damp indoor environments (Kay 2001; Adnan and Samsong 2011). In this study had been observed mould-fungi colonies in the wood boxes used to store potatoes. These wood boxes combined with local moisture content were the crucial factors for the development of fungi. The high levels of *Aspergillus/Penicillium* inside the cameras, the exposure to them of workers and the possible implications in their health should be considered a work risk. Then improvement of the materials for the potato storage and its hygienization is necessary for a safer environment. In the case of *Cladosporium*, the highest quantities were found in the warehouse with the ambient air system, but also lesser levels were present in the cooling system. Both genera include pathogenic fungi that can produce diseases as rhinitis, sinusitis, conjunctivitis, asthma or allergic alveolitis (Knutsen et al. 2012). In addition to the effects of these fungi in human health, the increase in their levels can be used as an indicator of the presence of damaged or rotting tubers. Despite the first damages cause for these pathogens in potato tubers not being described, they grow in wounds and over the surface of decayed tubers. Specifically, *Cladosporium* can grow and infects the fruit even at cold storage temperature thanks to the low minimal growth of temperature (-4°C) (Sommer 1985).

Some spores from common pathogens of potatoes were also detected in both warehouses but the prevalence of studied spores was higher in the ambient air system. The presence of *Alternaria*, *Fusarium*, *Helminthosporium* and *Phytophthora* (Fig. 2) stood out. All of them are from fungi species that are responsible for significant losses for farmers and industries. The most common was *Alternaria* in the ambient air system warehouse. It causes early blight, a common potato disease in a Limia (Escuredo et al. 2019; Meno et al. 2019). It appears first in the field and it is highly related to the weather conditions as an increase of temperature and drought favour the development of this fungus in the field (Abuley et al.

2018; Escuredo et al. 2011). Then tubers in the warehouse show the symptoms of the disease, with black and sunken lesions and internal brown to black corky tissues (Tsedaley 2014). Temperatures around 7°C decreased the level of *Alternaria* conidia in the air of the warehouse. On the contrary, when temperature increased to more than 10°C and the relative humidity was higher than 90%, the number of *Alternaria* spores increased. In the environment of the ambient air system warehouse and due to the period of storage (winter), temperature was low, but commonly during noon it increased so when the humidity was high, infection and sporulation were possible. Sporulation occurs between 5 and 30°C , with the optimum around 20°C (Abuley 2018). Moreover, alternating low and high humidity conditions favour disease development (Van der Waals et al. 2003). *A. solani* is one of the few pathogens that can overcome a lack of prolonged humidity, using several short and wet periods (usually at night) interrupted by dry intervals during the day, otherwise known as interrupted wet periods (Abuley 2018; Meno et al. 2019; Van der Waals et al. 2003).

Another well-represented fungus during all the period of storage was *Fusarium* having similar levels in both facilities. Some species such as *F. solani* and *F. oxysporium* affect potato crops during the growing crop. The first symptoms appear in the field in leaves and stems, being the primary source for the development of dry rot. The tubers show as initial symptoms shallow small brown lesions after approximately one month of storage (Bojanowski et al. 2013), however maximum levels were found when commercialization began, and tuber movements were intensified. Maximum peaks were when relative humidity was higher than 85% and temperature was higher than 9°C . With temperatures lower than 9°C , the concentration of *Fusarium* spores decreased. These results coincided with those presented by Secor and Salas (2001) in which infection of tubers caused by *Fusarium* occurred through wounds produced during harvest operations at temperatures higher than 10°C . Nevertheless, temperatures below 5°C inhibited the fungal growth. It is highlighted, this fungus is also associated with human diseases (Kulkarni et al. 2017).

Helminthosporium is another fungus for which the high levels in the air in both systems should be considered. At harvest time, the infected tubers have grey lesions on the periderm that appear to be silvery when wet. Under favourable storage conditions, the

fungal sporulation produces lesions and tubers ended black and sooty (Errampalli et al. 2001; Kutuzova et al. 2017). The ambient air storage system generates favourable conditions for the growth of *Helminthosporium* conidia. In the warehouse, the highest levels of *Helminthosporium* spores were registered at temperatures higher than 8 °C and relative humidity above 90%. This occurred starting the stored period probably due to the existence of old tubers inside the warehouse and at the end, when the spread of secondary inoculum caused an increase in the silver scurf incidence and severity. Conidia detach and move throughout potato storage facilities via air currents produced by the ventilation system, thus as storage time increases, levels of infection also increase (Secor and Gudmestad 1999). A new infection may occur when warm and humid conditions provoke the germination of the conidia (Rodríguez et al. 1996). According to Stachewicz et al. (2001), silver scurf can infect more than 50% of the tubers in the last stage of storage. This causes significant losses of tubers, for both fresh consumption and the processing industry (Hofmann 2009). Similarly as in *Alternaria*, higher temperature and higher relative humidity influenced the levels of *Helminthosporium* in warehouses.

A few sporangia of the oomycete *Phytophthora* were found in the air. As happened with early blight, episodes of late blight occur in A Limia every year, causing losses and considerable economical and environmental impacts due to fungicide use (Seijo-Rodríguez et al. 2018). Their presence in the warehouse is less common; however *P. erythroseptica* can produce pink tuber rot and *P. infestans* could also induce rot during storage (Hussain et al. 2013).

Traceability of potatoes from field plots to warehouses is fundamental, since frequently tubers were infected in the field or during the harvest (Pringle et al. 2009). Blows and wounds favour the contact of the spores with the tissues of the potatoes and, once in the warehouse, they are the raw material for infections. Moreover, collection of immature tubers due to their lack of skin, increases the risk of developing diseases such as dry rot (Bojanowski et al. 2013). The presence of injuries on the surface of the periderm, in addition to the accelerated moisture loss, is another factor that exposes the tuber tissues to pathogens, which can result in significant economic losses. Curing, as a prestorage treatment, is important in limiting weight loss and preventing the penetration of microorganism

(Pinhero et al. 2009). However, the use of facilities in poor hygienic conditions, with deteriorated tubers or tubers from previous crops contributes to the increase in these losses. Thus, at the beginning of the storage stage, relatively low levels of spores were registered in the ambient air system, but the spore concentrations increased as time passed. The first peak occurred a week before the storage started and approximately two weeks later, a new increment in the level of fungi was observed. The raises in the concentrations of spores in the environment is a consequence of the movements in the potato pile derived from maintenance operations such as tuber selection by hand. This increase was also observed after a month and a half of the storage period and much later when the commercialization of the tubers started. In the final stages of storage, the ageing of the tubers also contributes to create an ideal substrate for the development of the fungi (Escuredo et al. 2007). Handling potatoes stored in a pile causes movements of many of them. Thus, when marketing began, significant numbers of tubers move each time, causing the reorganization of the tuber pile and the release of spores. Similar situation occurs when farmers select potatoes in the same room.

A different situation was observed in the warehouse equipped with a cooling system. In this case, most of the fungal spore levels were low and constant during all the storage period. Only the presence of the *Aspergillus/Penicillium* group was clearly higher. The potatoes were moved within the boxes having the lesser influence on environment than handling in tuber piles. Furthermore, in this warehouse the tuber selection occurred in a different emplacement.

In addition to the movements of the tubers inside warehouses, variations in the spore levels during storage, could be related to the use of controlled environments. Temperature and humidity are the most important variables influencing the growth of fungi and the production of spores (Escuredo et al. 2011; Fernández-González et al. 2013; Gomez de Ana et al. 2006; Grinn-Gofroń et al. 2019; Seijo-Rodríguez et al. 2018). As several authors documented, temperature is the most important factor to safeguard the quality of stored potatoes (Pinhero et al. 2009; Pringle et al. 2009). As it is well known, temperature is closely related to relative humidity as warm air holds more moisture than cold air. Thus, even small changes in temperature can cause dramatic changes in relative humidity. The increase in temperature above 10 °C

and relative humidity higher than 90%, even for a short period, can favour the fungi growth (Hatzipapas et al. 2002). Canonical correlations endorse this fact showing that the relative humidity and maximum temperature were the most important variables in the set of environmental conditions. The ambient air system storage environment, in which temperature had the greatest oscillation and relative humidity was high, had a greater diversity and higher content in fungal spores than the cooling system. Even more some fungi as *Cladosporium*, *Helminthosporium* and *Alternaria* were present in important quantities. Masangkay et al. (2000) stated that the conditions of darkness (normal conditions in the tuber storage), facilitate germination, and subsequent sporulation of these fungi when optimal conditions are reached.

The disease development can affect the quality and health of potatoes (Secor and Gudmestad 1999). Its consequences are more serious when combined with mechanical damage resulting from handling and transportation as well as uncontrolled conditions of temperature and humidity (Pinhero et al. 2009). Considering the obtained results and the consequences of pathogenic fungi behaviour, monitoring the way from the cultivation field to the warehouse, together with the implementation of appropriate storage systems would be a useful tool to reduce postharvest losses.

5 Conclusion

The environment of the potato warehouse contains a great diversity of spores with *Aspergillus/Penicillium*, *Cladosporium*, *Alternaria*, *Fusarium*, *Helminthosporium*, *Leptosphaeria* and *Stemphylium* being the most representative. Some of these fungi can affect human health, and others such as *Alternaria*, *Fusarium*, *Helminthosporium* or *Phytophthora* are known for their pathogenicity in potatoes. Temperature, high relative humidity and fluctuations of both of them during the storage period favour the proliferation of fungi, especially *Cladosporium*, *Alternaria* and *Helminthosporium*. The most common fungus in the cooling system was *Aspergillus/Penicillium* and to a lesser extent *Cladosporium* and *Fusarium* conidia. Furthermore, the management of the tubers in the warehouse was related to the increase of the fungal elements causing a very high level of spores at the end

of the storage period. Good harvest and postharvest practices together with the prophylaxis of the facilities and good ventilation could be helpful in reducing the incidence of the fungi. The monitoring of spores in the environment can contribute to detecting the presence of pathogenic fungi and to preventing economic losses.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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