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"Phytopathological strolls" in the dual context of COVID-19 lockdown and IYPH2020: Transforming constraints into an opportunity for public education about plant pathogens

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Abstract

The experience presented here relates to 2020, a particularly timely year for plant disease-related communication (International Year of Plant Health, IYPH2020), but also a unique year because of the COVID-19 pandemic. Our goal was to illustrate the diversity and beauty of fungal plant pathogens through a naturalist approach that could be followed by any amateur. We achieved this end through "phytopathological strolls", in which we observed and determined the origin of symptoms on diseased plants found in our garden, in the local streets, and in nearby open spaces, and shared this matter with a broad public. The lockdown imposed in France created an additional motivation to take up the challenge, and to involve our children, even under strong constraints such as movement restrictions. We observed and described fungal pathogens through hundreds of photographs, shared our findings with a large audience on Twitter, and received feedback. The material used was deliberately simple and transportable: a digital reflex camera, an old microscope, a mobile phone, some books, and an internet connection. Between 17 March 2020 and 20 June 2021 we found 196 plant pathogens, including 97 rusts, 27 powdery mildews, and 28 septoria-like diseases. We discuss here the importance of promoting searches for plant pathogens, their description and conservation, through a combination of classical approaches and digital tools in tune with the times, such as Twitter, by treating pathogen identification like a detective game and, more surprisingly, by making use of the addictive nature of collection approaches, drawing a parallel with Pokémon GO.

KEYWORDS
education, fungal pathogen, lockdown, rust

1 | INTRODUCTION

Plant pathogens are harmful to crops and have, over the centuries, caused famines, ruined economies, and blighted landscapes. However, looking at these pathogens from a naturalist viewpoint, rather than in an agricultural context, we wondered whether it was possible to consider plant diseases, especially those caused by fungi, differently, given their rarity, diversity, and even beauty. This attitude is at odds with the perception of plant diseases among farmers and most plant pathologists, who are not used to approaching this subject from this angle. Like most plant pathologists, we typically start our scientific articles by describing the severity of crop losses and justifying our choice of study model as one of the principal diseases responsible for such losses. However, we are also struck by the beauty of some of the symptoms we observe, even if we generally prefer not to point this out to farmers (for whom these "beautiful" symptoms may spell financial disaster due to crop losses) or to friends and family unlikely to share our enthusiasm. As a result, the enjoyment of plant diseases is a somewhat solitary pleasure that can be shared only with colleagues, and potentially with partners or, more rarely, with children. We wonder whether, as plant health professionals, it might be possible to adjust our perspective and adopt a naturalistic approach not only for the overall surveillance of pests, but also to observe and share the beauty of fungal plant diseases. The second part of this question may appear frivolous in the context of a scientific journal such as *Plant Pathology*, but we are convinced that this aspect deserves greater attention, if only to improve the communication of our discipline to a broader public by a means other than cutting-edge or technological science. Improving our observation of our environment and getting to know it better could be highly beneficial in a number of ways.

The "One Health" paradigm emerged in the context of the increasing domination of our planet by human activities and is highly influential at the moment. This paradigm, the theme of the current *Plant Pathology* special issue, renders the concept of health more inclusive, by considering humans, domestic and wild animals, cultivated and wild plants to be indissociable (Cumming & Cumming, 2015). Fungal diseases of plants are a particularly important component of One Health, as they can contribute directly to the degradation of agrosystems (Desprez-Loustau et al., 2007; Fisher et al., 2012), but also to the emergence of outbreaks with major but indirect consequences for animal and human health (Konopka et al., 2019). It is thus becoming increasingly important for pathologists to raise the awareness of policymakers concerning established and emerging fungal threats to food security and global health. However, causing fear is rarely a helpful strategy for communication. Admiring a human or animal disease would not be ethical, and, even if it were, it would be impossible to share this admiration with a wide audience from a purely naturalistic standpoint. Medical and veterinary doctors generally care for individual humans or animals. By contrast, "plant doctors" rarely care for single plants (except for certain heritage trees or pot plants). Instead, they aim to improve the health of a whole plant population at the field or ecosystem scale. This makes it possible for everyone to observe single diseased plants in familiar places without apprehension or disgust, for the purposes of education or to inspire new vocations.

Plant health can be explored distinctively by a naturalist or normativist approach (Döring et al., 2012), if the observer is a farmer or an amateur botanist, for example. The naturalist concept of plant health proposed by Boorse (1977) was described by Döring et al. (2012) as a "circular argumentation" because it defines health as an absence of disease, whilst defining disease as being "inconsistent with health". Plant diseases are often visible to the naked eye, even though they are caused by microorganisms, and the symptoms may be "beautiful" in the eyes of an amateur naturalist. Conversely, according to normativism, all measurements of a disease, including those obtained through biological sciences, have a cultural dimension and cannot, therefore, ever be completely objective. As a consequence, the search for diseases during strolls, as proposed here, is biased, because it results from an arbitrary choice: looking at a plant with flagrant symptoms rather than a plant that appears normal but has been physiologically weakened by a disease, or being attracted to rare symptoms (not seen elsewhere) rather than common ones.

The United Nations General Assembly declared 2020 as the International Year of Plant Health (IYPH2020), with various objectives, including raising public awareness in a massive manner as concerns the protection of the environment and facilitation of economic and trade development, and the promotion and strengthening of global, regional, and national plant health efforts (Routray, 2020). The objective of the experience reported here is consistent with the objectives of IYPH2020, namely informing, educating, and engaging audiences through the sharing of knowledge about fungal pathogens on digital social media. Our goal was to illustrate the diversity and beauty of fungal plant pathogens through a naturalist approach that could be followed by any amateur in any place colonized by plants, whether in a natural, rural, or urban area. We used a strategy based on local "phytopathological strolls", in which we observed and determined the origin of symptoms on diseased plants, sharing our exploits with the broad general public, from the scale of our family to a global social network, through the popular microblogging social media platform Twitter. The approach was simple: observe, describe through photographs, identify with simple means, share with a large audience, and receive feedback. This experience was initiated in 2020, a particularly timely year for communicating about plant diseases (IYPH2020) embracing the One Health paradigm, and very unusual because of the COVID-19 pandemic. The lockdown implemented to control this pandemic created a new motivation in our lives to take up this challenge under the imposed constraints, such as travel restrictions. We were convinced that illustrating the diversity and beauty of plant pathogens would be all the more effective and striking under these uniquely constrained conditions. The problem of collection is that its potentially unlimited nature can be daunting. The constraints of lockdown actually resolved this problem by forcing us to confine our efforts to short outings close to home.

2 | MATERIALS AND METHODS

2.1 | Context of strolls

There have been three lockdowns so far to counter the COVID-19 epidemic in France. The first extended from 17 March to 11 May 2020 (55 days), the second from 30 October to 15 December 2020 (47 days), and the third from 3 April to 3 May 2021 (28 days). Our phytopathological strolls began at about the same time as the first lockdown and were completed some weeks after the end of the third lockdown. During the first lockdown, all the members of our family stayed at home (traditional single-family house with a garden) in Les Clayes-sous-Bois, about 30 km west of Paris (48°49′14″N, 01°59′33″E). We worked from home, the children had online lessons, and we went out only to shop for food and to get some fresh air, initially in the nearby streets (as all parks and forests were closed to the public during the first few weeks) and later in open spaces (walks in a small park and in a nearby forest, such outings being limited to a radius of 1 km and a duration of an hour), or, exceptionally, to go to the INRAE laboratory and greenhouse at Thiverval-Grignon (48°50′49″N, 01°56′34″E) to deal with scientific and technical emergencies. The second lockdown was less strict. We worked from home 2–3 days per week and were allowed to walk for up to 3 hours at a time, within a radius of 20 km from our home. The third lockdown was quite similar to the second one but we decided to spend it partially in alternative homes in the south-west of France. We saw every stroll as an opportunity to search—in our garden, the street, the urban green spaces, or the INRAE arboretum—for all plants with visible symptoms on leaves. Between the lockdown periods, constraints were eased to such an extent that travel was possible, so we extended our search to various holiday destinations, such as Millau (44°05′50″N, 03°03′22″E) and Sermizelles (47°32′20″N, 03°47′33″E), and to weekend getaways (Figure 1).

2.2 | Materials

We deliberately chose to use simple and transportable material within the reach of any amateur naturalist. During our communications, we made it clear that the various observations and identifications could be made by anyone looking at a plant with symptoms, without the need for specialist analytical techniques. The "old-school" material used (Figure 2a) probably gave a cliché image of what it is like to be a plant pathologist in 2020. *In natura* photographs were taken with a Canon EO7D digital single-lens reflex camera with a 100 mm macro lens (Canon, Inc.) and a Panasonic Lumix Dmc-Fx37 digital camera (Panasonic Corporation). Microscopy preparations were classically wet mounts, in which fine slices of tissues showing symptoms were placed in a drop of water with some methylene blue held between a glass slide and a coverslip. We used a pin and a scalpel to prepare the slides, and a white ceramic tile was used as a transportable laboratory bench. Microscopy observations were performed with an old SM-M Leitz binocular microscope with a black enamel finish (c.1965; Ernst Leitz GmbH) operating with four lenses: 3.5×, 10×, 40×, 100×, and two eyepieces: 10×, 1.25× (Overney & Overnay, 2008). Photographs of the microscope slides were taken with a Galaxy A40 (Samsung Electronics) mobile phone held by hand directly above the eyepiece of the microscope. The microscopy slides were sealed with nail polish and kept in a dedicated box. Diseased plant samples were pressed and protected with paper to build up a small herbarium.

We deliberately limited the bibliographic references used, focusing on two books on plant pathogens (Gäumann, 1959; Klenke & Scholler, 2015; Sprague, 1950; Viennot-Bourgin, 1949) together with articles from a wide range of scientific journals. We used a few websites and blogs written by plant pathologists (e.g., Ellis, 2020; Kruse, 2020; Lechat, 2020; Sothmann, 2020). We also used basic botanical guidebooks to identify the host plants, particularly for difficult groups, such as Poaceae or *Carex* (e.g., Fitter et al., 2016), and endemic species (e.g., Coste, 1887). We also used the Pl@ntNet mobile phone application (PlantNet Consortium, 2020), which was very useful for confirming identifications during walks. All samples were prepared and identified at a desk, which was not always in the same location—at home in Les Clayes-sous-Bois (Figure 2b), during holidays in Millau (Figure 2c) or in Sermizelles (Figure 2d)—but always in the same pleasant old-school atmosphere.

2.3 | Public social media as a communication channel

The potential of social media is now largely recognized in science, especially in the environmental and ecological fields. The value of non-expert observations has been highlighted by the increasing number of individual initiatives from passionate amateurs or so-called "citizen science" projects accessible via websites or mobile applications (Daume & Galaz, 2016; Silvertown, 2009). Microblogging

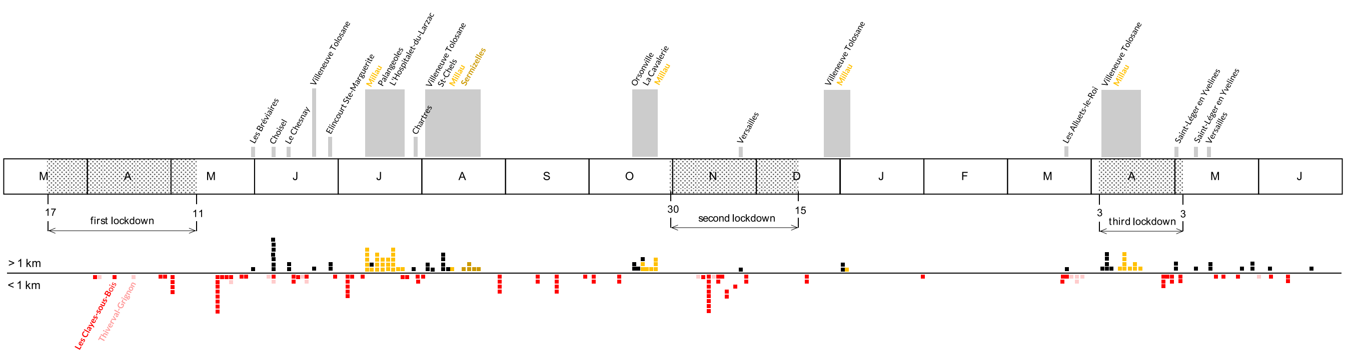


FIGURE 1 Distribution in time and space of our 2020 "phytopathological strolls" in the context of the COVID-19 pandemic (see also the map in Figure 4). Each square indicates that a plant disease was photographed, collected, and identified (first occurrence only). The colour of the square corresponds to the location. Grey rectangles indicate locations accessed after travel and their sizes are proportional to the distance from our home and to the duration of our stay. The prospecting perimeter around our home (Les Clayes-sous-Bois) and the INRAE workplace (Thiverval-Grignon) corresponded to the perimeter authorized during the first lockdown (<1 km)

FIGURE 2 (a) Material used at home and microscopic observation areas for our 2020 "phytopathological strolls": (b) Les Clayes-sous-Bois (Yvelines), (c) Millau (Aveyron), and (d) Sermizelles (Yonne)

social media platforms for short messages (e.g., Twitter) are also used by many academic scientists as an informal arena for previewing work underway or for amplifying the impact of their publications (Darling et al., 2013). Furthermore, these platforms are appreciated in the day-to-day communication of scholars, as a means of actively engaging with the public and influencing perceptions about science (Ke et al., 2017). Our own experience on Twitter shows that the plant pathologist community is well developed and active. In this context, Twitter was the only tool used to communicate our findings. We used our personal accounts (mainly @wheatpath, but also @MurielSuffert for fuelling and sharing conversations), both created in 2012, with 2725 and 2345 followers, respectively, on 20 June 2021. We published hundreds of photographs of the plant pathogens that we found, presented their characteristics and discussed their identification in messages of limited size (<280 characters). In some cases, we developed threads (groups of related tweets) for educational purposes providing more detailed explanations and bibliographic references, particularly during the first lockdown. This mode of communication was exclusive. We deliberately decided not to discuss this experience with our INRAE and EPPO coworkers, with the exception of those with an active Twitter account.

3 | RESULTS

3.1 | Photographs and descriptions of plant pathogens discovered during our strolls

We found and photographed pathogens causing 196 diseases: 97 rusts, 27 powdery mildews, 28 septoria-like diseases, 30 other fungal leaf diseases, 8 other fungal non-leaf diseases, 3 hyperparasite fungi, and 3 non-fungal diseases (Table S1). These findings clearly demonstrate that it is possible to find a large diversity of plant pathogens in a relatively restricted area (Figures 3 and 4). An example of a sheet for a pathogen is presented in Figure 5, and all 196 sheets are available from Appendix S1, the core output of this experience.

FIGURE 3 Illustration of our 2020 "phytopathological strolls" in a familial context. (a) Cover of *Petasites hybridus*, host of *Coleosporium tussilaginis* f. sp. *petasitis* (Les Clayes-sous-Bois, 2020-06-07; Appendix S1, sheet no. 3). (b) "Beastie the bug" (@bug_beastie), mascot of EPPO travelling the world to raise awareness on plant health during the IYPH2020, here presented in *Pyrus communis*, host of *Gymnosporangium sabinae* (Millau, 2020-07-12; Appendix S1, sheet no. 7). (c) Photograph of *Uromyces trifolii-repentis* on *Trifolium pratense* in the garden of our home (Clayes-sous-Bois, 2020-04-26; Appendix S1, sheet no. 96). Practical work session during home schooling with our two youngest children: (d) in situ observation of *Puccinia lagenophorae* on *Senecio vulgaris* (Les Clayes-sous-Bois, 2020-03-29; Appendix S1, sheet no. 58); (e,f) microscopy observation; (g) diagnosis of *Phragmidium rubi-idaei* infection on a leaf of *Rubus idaeus* (Clayes-sous-Bois, 2020-06-05; Appendix S1, sheet no. 27) based on Viennot-Bourgin (1949)

We were able to identify 158 of the 196 pathogens to species level without difficulty (sometimes after misidentification, corrected after posting on Twitter with the help of plant pathology experts and amateurs), and 27 with reasonable doubt. The identification of 12 other pathogens was uncertain, or limited to genus level, as for *Melampsora* sp. on willows, *Puccinia* sp. on sedges, or *Erysiphe* sp. These identifications are known to be problematic even for specialists (Pei & McCracken, 2005).

3.2 | Some uncommon species

The vast majority of species we found are common in France, but some were quite rare or had never been reported in France or in Europe. For instance, we found *Uromyces plumbarius* on biennial gaura (*Oenothera gaura* syn. *Gaura biennis*) in a flowerbed just in front of our daughter's school in Les Clayes-sous-Bois (Appendix S1, sheet no. 93). To our knowledge, this is the first time that this species has been reported in Europe (Bisby, 1916; Hennen & Cummins, 1967; Kern & Whetzel, 1926). For confirmation of this observation as a first detection in Europe, this identification would need to be completed by a molecular method (e.g., ITS sequencing), but the likelihood of this identification being confirmed is high, as no rust has ever before been described on biennial gaura in Europe (Klenke & Scholler, 2015). This ornamental species was imported from North America and its identification was certain in this case. We found *Septoria caricis* on specimens of grey sedge (*Carex divulsa* subsp. *divulsa*) growing in the gutter along a street in Villeneuve-Tolosane (Appendix S1, sheet no. 142). The leaves presented irregular spots, elongated parallel to the veins, with pycnidia releasing fusiform pycnidiospores, and morphological characteristics sufficiently distinctive to allow the identification of this fungal species with a high degree of certainty. To our knowledge, this is the first record of this fungal pathogen on this host plant in continental Europe: *S. caricis* has been reported on *Carex* sp. throughout the world (Bulgaria, Canada, China, Iceland, Poland, Romania, USA, Uzbekistan) but on *C. divulsa* only in the Canary Islands (Jørstad, 1958) and Turkey (Erdoğdu & Özbek, 2017). We found *Blumeriella kerriae* on a Japanese marigold bush (*Kerria japonica*) in both an urban horticultural garden in Chartres and a private garden in Villeneuve Tolosane (Appendix S1, sheet no. 157). This pathogen causes leaf spots and was described for the first time in the UK only recently (Robinson et al., 2017; Stewart, 1917). Its identification at two distant sites during our strolls suggests that this species may

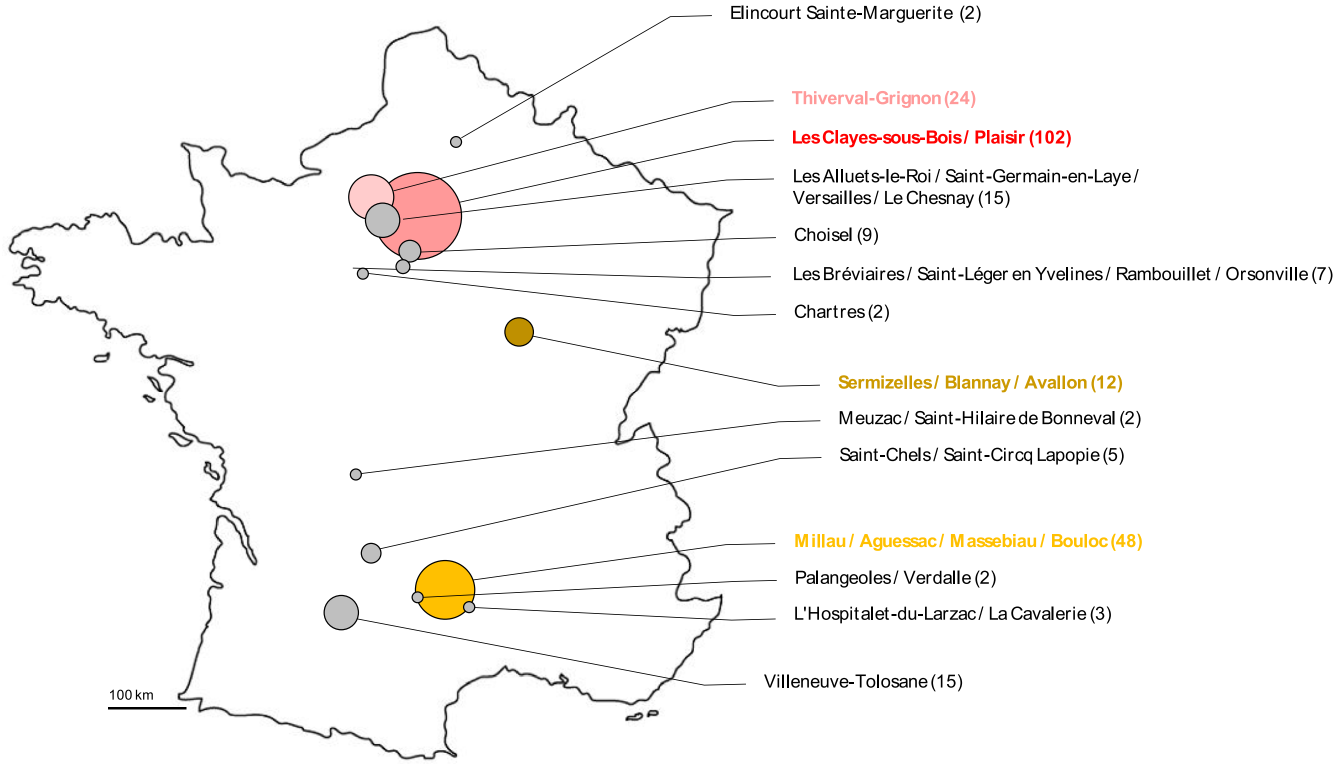
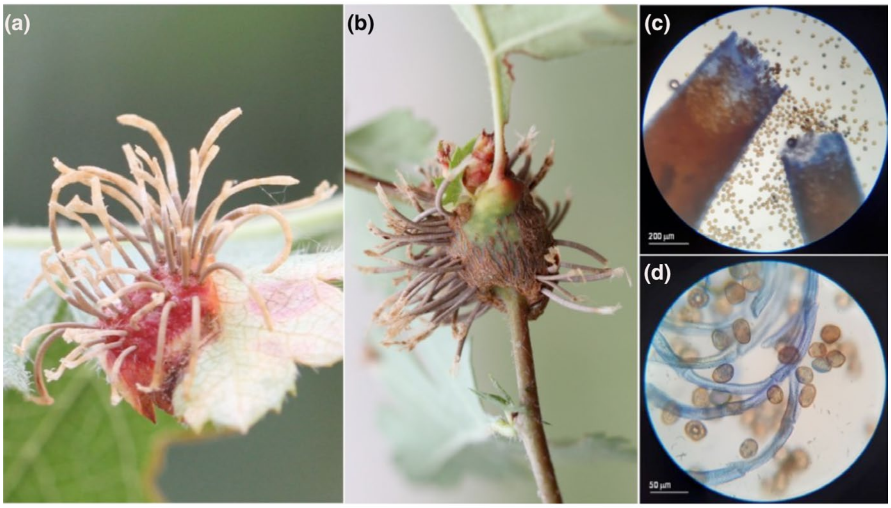


FIGURE 4 Location of the plant pathogens identified (first occurrence) during our 2020 "phytopathological strolls" in France from 17 March 2020 to 20 June 2021. The size of the circles is proportional to the number of plant pathogens

be widespread in France despite never having been officially reported. We found the widespread pathogen species *Microbotryum dianthorum* on *Dianthus longicaulis* (Appendix S1, sheet no. 185), a rare plant endemic to France, at L'Hospitalet-du-Larzac on the Larzac Causse (Coste, 1887). To our knowledge, this fungus, which causes anther smut disease, has never before been described on this carnation species. We found what appeared to be a secondary fungal pathogen on the leaves of a Japanese spindle tree (*Euonymus japonicus*) infected with the common powdery mildew pathogen *Erysiphe euonymi-japonici* (Appendix S1, sheet no. 104). A recent phyllosphere microbiome study (Zhang et al., 2019) showed that the genera most frequently found on the leaves of *Erisyphe* were *Pleosporales* and *Alternaria* (>10% of total sequences). Based on spore morphology, we therefore suspected this secondary pathogen to be *Alternaria tenuissima* (Appendix S1, sheet no. 153), which had already been identified on this host species, although attempts at host reinfection were not successful (Safari Motlagh & Bayegan, 2014). We also found *Phaeobotryosphaeria visci* on European mistletoe (*Viscum album*) in many locations (Appendix S1, sheet no. 133). This fungal pathogen received very little attention in France, although it was reported to be a potential candidate for biological control (Varga et al., 2012), an interesting perspective as mistletoe is abundant in the trees of the French countryside. These six examples show that it is not rare to detect new occurrences of plant pathogens. Species can be identified morphologically with simple material, although more formal investigations would be required for confirmation of the identification. Organisms living in harmony with their host in a particular country may become invasive or pathogenic when introduced into new areas (e.g., Seebens et al., 2018). It is therefore useful to have records of native plant pathogens, to make it possible to trace their origins.

3.3 | Diversity of epidemiological stages and the search for alternate hosts: more fun than detective games?

Two of the 97 rust pathogen species we identified were found at all four epidemiological stages (pycnida, aecia, uredinia, telia), on the same host species for *Cumminsiella mirabilissima* (*Mahonia aquifolium* syn. *Berberis aquifolium*; Appendix S1, sheet no. 5) and on three different hosts for *Puccinia sessilis* (*Arum maculatum*, *Polygonatum multiflorum*, and *Phalaris arundinacea*; Appendix S1, sheet no. 74). Six were suspected to be present at three stages on the same host (*Puccinia lapsanae* on *Lapasana communis*; Appendix S1, sheet no. 60) or on two different hosts (*Gymnosporangium clavariiforme* on *Crataegus monogyna* and *Juniperus communis*, *Puccinia caricina* var. *ribesii-pendula* on *Ribes rubrum* and *Carex pendula*, *Puccinia clematidis-secalis* or *Puccinia agropyri* on *Clematis vitalba and Elymus campestris*, *Puccinia urticae-hirtae* on *Urtica dioica* and *Carex hirta*, and *Uromyces dactylidis* on *Ficaria verna* and *Dactylis glomerata*; Appendix S1, sheet nos. 6, 42, 44, 80, and 87, respectively). Forty were found at two developmental (a,b). Peridia on diseased leave and stems (*Crataegus monogyna*). (c,d). Aeciospores. Millau, 2020-07-17.



(a,b). 'Telial horns' on branch (*Juniperus communis*). (c,d). Teliospores. L'hospitalet-du-Larzac, 2021-04-12.

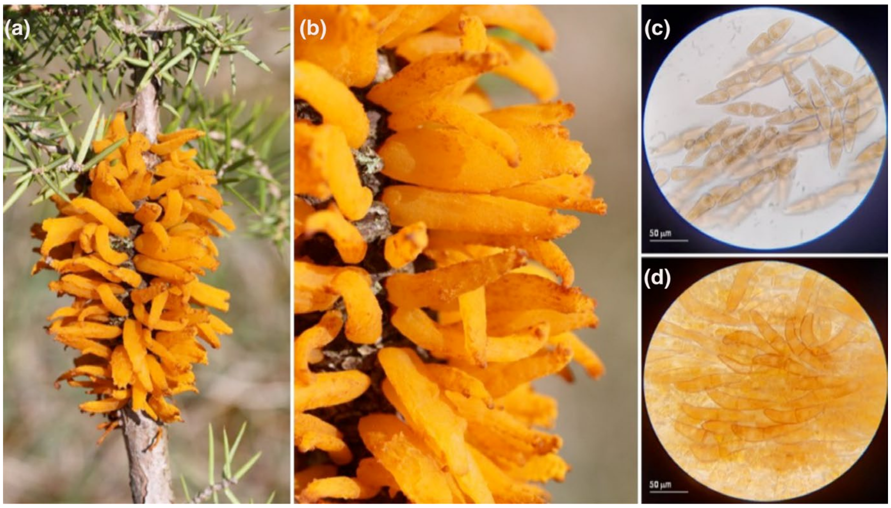


FIGURE 5 Example of a plant pathogen sheet (*Gymnosporangium clavariiforme* on *Crataegus monogyna* and *Juniperus communis*; sheet no. 6) from the 196 presented in Appendix S1

stages (32 uredinia-telia, 6 pycnia-aecia, 2 aecia-uredinia) and 49 at only one stage (30 uredinia, 13 telia, 6 aecia). It was not possible to establish unequivocally that the six aforementioned rust specimens on two different hosts belonged to the same species, but the level of suspicion was high for *G. clavariiforme* (Millau), *P. caricina* var. *ribesii-pendula* (Orgeval), and *P. clematidis-secalis* or *P. agropyri* (Millau), as for *Puccinia urticae-acutiformis* found at the aecia and telia stages (Orgeval; Appendix S1, sheet no. 79; Appendix S2, conversation P), because we found the two infected hosts on the same day, separated by only a few metres. The identification of the rust found on *C. pendula* at Les Clayes-sous-Bois as *P. caricina* var. *ribesii-pendula* (Appendix S1, sheet no. 42), was uncertain. Indeed, we found uninfected specimens of the alternate host (*R. rubrum*) of this species in close proximity (<10 m), and uninfected specimens of the alternate hosts (*Tussilago farfara* and *U. dioica*) of *Puccinia petasites-pendulae* and *Puccinia urticata*, respectively, which can also attack *C. pendula* (Klenke & Scholler, 2015), a bit further away (50–300 m). For the 27 powdery mildews that we found, the perfect stage (sexual) was observed in 15 cases, rendering species identification much more reliable, based on the morphology of the cleistothecia (size, appendages) and asci (shape and number of ascospores).

3.4 | Fungal plant diseases are beautiful

Common pathogenic species with particularly aesthetic forms were observed, including *Rosa* sp. fruits contaminated with *Phragmidium mucronatum* resembling olives stuffed with peppers (Appendix S1, sheet no. 26). We also observed a number of other attractive structures for which we posted photographs on Twitter. These structures included columns of *Cronartium flaccidum* teliospores on *Paeonia lactiflora* (Appendix S1, sheet no. 4), tubes containing *G. clavariiforme* aeciospores on leaves and stems of *C. monogyna* (Appendix S1, sheet no. 6), and lantern-shaped growths containing *Gymnosporangium sabinae* aeciospores on *Pyrus communis* (Appendix S1, sheet no. 7). We also found spots on leaves of *Sambucus nigra* caused by *Cercospora depazeoides*, with such a beautiful graphical aspect that we presented this disease as "snake-skin disease" (Appendix S1, sheet no. 160).

3.5 | Pathogenic fungi are not the only outstanding feature of diseased plants

On some diseased plants, we found small animals associated with the fungal pathogen. For instance, we observed slugs feeding on *Coleosporium tussilaginis* f. sp. *petasitis* telia on *Petasites hybridus* (Appendix S1, sheet no. 2), with orange excrement containing the remains of teliospores. Interestingly, this observation was consistent with previous findings that some mollusc species prefer grazing on plants infected with rust fungi (Hajian-Forooshani et al., 2020; Ramsell & Paul, 1990). On various rust-infected plants, we found larvae of *Mycodiplosis* sp. feeding on (a) aecia of *Melampsora euphorbiae-dulcis* on *Euphorbia lathyris* (Appendix S1, sheet no. 16) and (b) uredinia of *Melampsora euphorbiae* on *Euphorbia amygdaloides* (Appendix S1, sheet no. 15), *Melampsora hypericorum* on *Hypericum perforatum* (Appendix S1, sheet no. 17), *Melampsora* sp. on *Salix atrocinerea* (Appendix S1, sheet no. 22), *Puccinia antirrhini* on *Antirrhinum majus* (Appendix S1, sheet no. 35), *Puccinia menthae* on *Mentha aquatica* (Appendix S1, sheet no. 63), and *Puccinia sessilis* on *Polygonatum multiflorum* and *Arum maculatum* with a nymph of *Symphypleones* sp. (Appendix S1, sheet no. 74). We observed and described an emblematic example of mutualistic symbiosis between a grass (*Dactylis glomerata*), a fungal endophyte (*Epichloë typhina*), and an insect (*Botanophila* sp.; Appendix S1, sheet no. 183). In a dedicated thread on Twitter, we thus presented several photographs of fungal stromata of *E. typhina* found on the sheath of the flag leaf of *D. glomerata* in the forest of Rambouillet (Bultman & Leuchtmann, 2008; Viennot-Bourgin, 1949). Most were still immature (white), but a few (turning orange) displayed the initiation of perithecia, the sexual stage of the fungus. We explained that the stromata are usually visited by *Botanophila* sp. flies, for feeding and egg laying, serving as the vector of spermatia and mediating cross-fertilization in *E. typhina*, which is a heterothallic obligate out-crosser. We presented photographs with *Botanophila* sp. eggs and larval brood chambers, which we found on >85% of the stromata (on average, 4–5 per stroma), consistent with the findings of Górzyńska et al. (2010). A similar, but less common, interaction was found on *Brachypodium pinnatum* subsp. *rupestre* with *Epichloë sylvatica* (Appendix S1, sheet no. 184). We also observed aphids, such as *Macrosiphoniella artemisiae* on *Artemisia vulgaris*, but found no records of interactions established with the pathogen *Puccinia artemisiella* (Appendix S1, sheet no. 37). Finally, we identified three hyperparasite fungi: *Ampelomyces quisqualis* with *Golovinomyces cichoracearum*, *Tuberculina persicina* with *Puccinia sessilis*, and *Tuberculina sbrozzii* with *Puccinia vincae* (Appendix S1, sheet nos. 191–193).

3.6 | Communication on Twitter

All 196 pathogens were presented in Twitter messages or threads, with the support of one or several photographic sheets, generally posted within 2–3 days of observation of the symptoms. Three examples of Twitter conversations from these messages are presented in Figure 6, and a dozen more are shown in Appendix S2. The various messages were intended for the general public, but also for specialists (farmers, scientists, students). We explained some of our practical activities, sometimes involving our children (Figure 3). Several comments from other plant pathology experts helped us to identify the pathogen species when our initial identification was erroneous or uncertain (Appendix S2, conversations G, H, and I). Fruitful interactions occurred in the particular context of IYPH2020, promoted

FIGURE 6 Three examples of conversations on Twitter from a dozen such conversations presented in Appendix S2

by the International Plant Protection Convention (@ippcnews) with the EPPO mascot "Beastie the bug" (@ eastiebug), the British Society for Plant Pathology (@BS_PP) with the #WildPlantDisease and #WildFlowerHour challenge in August 2020 (Appendix S2, conversation B), the French Phytopathological Society (@SFP_France), and the Plant Health and Environment SPE INRAE division (@ INRAE_DPT_SPE) (Appendix S2, conversation A). Educational aspects were highlighted in several threads, mostly in English but sometimes in French, during the first lockdown, during which we had to organize home schooling (Appendix S2, conversations C, D, E, and F). We adopted an ironic tone on several occasions, considering that visual or situational jokes might make the conversation more attractive (Appendix S2, conversations K, L, M, N, O). From 17 March to 20 June 2021, the messages relating to the 196 plant pathogens (single tweets or threads) on the @wheatpath account received a total of 5953 engagements (on average, 33 likes, retweets, citations, or responses per conversation). We analysed the number of engagements according to disease category (rusts, $n = 97$; powdery mildews, $n = 27$; septoria-like diseases, $n = 28$; other fungal leaf diseases, $n = 30$; other fungal non-leaf diseases, $n = 8$; hyperparasite fungi, $n = 3$; non-fungal diseases, $n = 3$; Table S1), and the results of this analysis are presented in Figure 7. If we consider the number of engagements to reflect interest in the pathogen presented (although there are, obviously, multiple biases), we can conclude that rusts are the most attractive plant diseases (on average 42 engagements per species), ahead of powdery mildew (28 engagements). Septoria-like diseases and other fungal leaf diseases were much less popular (19 engagements). We can explain these results by the nature of @wheatpath followers, some of whom are rust specialists, and by the attractive profile of rusts: they present considerable diversity, with many species, and a number of beautiful and diverse structures (stages 0 to IV). These characteristics are of a type likely to appeal to naturalists and collectors (see the discussion of Pokémon GO below).

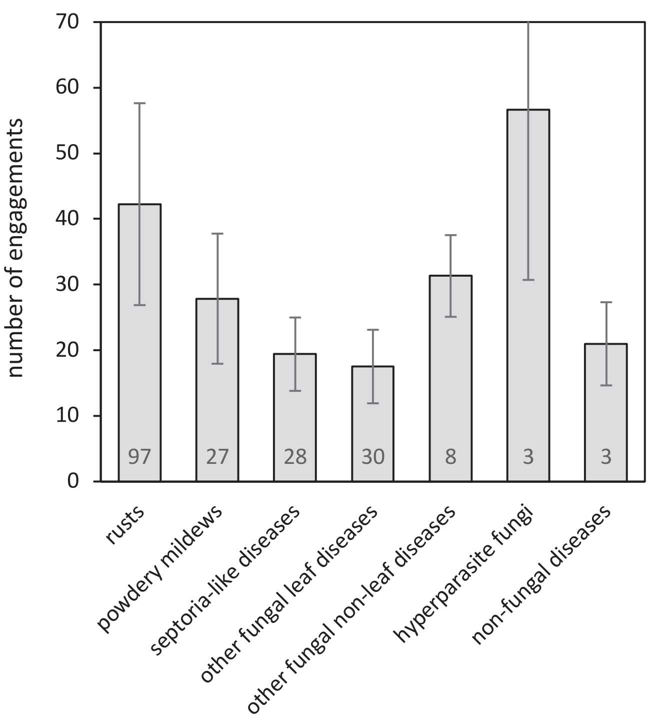


FIGURE 7 Preference for different categories of disease on Twitter based on the mean number of engagements (like, retweet, citation, or comment) for each tweet (unique message or thread). For each category, the number of diseases (total = 196) mentioned in at least one tweet is indicated. Bars indicate the standard deviation

Finally, our children were very interested in this experience, both in terms of the search for samples during strolls and the microscopy observations at home. Of course, these strolls also provided an opportunity to observe nature in general and to identify interesting other fungi, insects, and plants, but we do not deal with this aspect here.

4 | DISCUSSION

4.1 | Reviewing individual diseased plants: how can we highlight host–pathogen pairs?

The COVID-19 lockdowns have proved a real challenge for us, both professionally, as a scientific researcher focusing on plant health at a national institute (INRAE) and a scientific officer in an intergovernmental organization (EPPO), and as parents responsible for educating our children (6, 12, and 13 years old) at home to compensate for school closures. This unusual experience showed us how difficult it can be to run experiments when access to laboratory facilities is limited, to coordinate meetings when colleagues cannot travel, and to ensure that projects reach their milestones, in a broad sense, while keeping children motivated and curious about life in a situation in which working from home has to be combined with home schooling. However, as shown by this article, these conditions also provided us with a tremendous opportunity to find new inspiration in plant pathology, in our surroundings, away from our usual work routines. Over the last year, we have seen many academic and non-academic colleagues taking the time to observe carefully and document many wild plants or pathogens on Twitter (see, for instance, the hashtags #WildPlantDisease, #WildFlowerHour, #MoreThanWeeds, and #PavementPlants promoted by @BS_PP, @BSBIbotany, @wildflower_hour, and @morethanweeds, or the @RPilze @SebbyRust, and @pascal_frey personal accounts). Several of the plant pathogens found came from neglected urban areas (vacant green areas, waste ground, unmaintained portions of pavement, for example), highlighting a strong contrast in the naturalist curiosity of attractive and ephemeral biological structures found in ordinary, sometimes ugly, environments.

The COVID-19 lockdowns placed the spotlight on nature within urban areas, encouraging people to take a fresh look at the green areas around them. They have had a marked effect on citizen science projects, in Australia and South Africa for example, increasing the public response to initiatives for obtaining data on birds (Reside et al., 2020; Rose et al., 2020) or the flowering behaviour of grasses (Van Haeften et al., 2021). Moreover, bird watching was found to bring happiness to the observers in this difficult context

(Nairn, 2020). In our opinion, observing plants and looking for their pathogens is as easy as bird-watching, and probably brings similar satisfaction to those practising it. As pointed out by Döring et al. (2012), there is no reason why healthy plants should be preferred over their pathogens, at least those that cause non-lethal infections. We are thus tempted to turn the adage "what doesn't kill me makes me stronger" into "what doesn't kill me makes me more attractive": plant pathogens can be remarkable, in the most literal sense; they deserve to be "remarked", that is, to be seen, looked at, described, photographed, shared, and used for emotional (artistic) or educational purposes. We show here that it is easy to develop such an approach within very limited spatial and logistic constraints, so long as there is a will and desire to do so. Our connections with some of our plant pathologist colleagues on Twitter helped us to get through lockdown by keeping us engaged with science while creating opportunities for engagement, whether with our children educated at home, or through communication with a broader public. Like Yannelli and Saul (2020), we found that despite (maybe even thanks to) the limitations and difficulties associated with lockdown, everybody can explore their immediate surroundings and discover the diversity and beauty of plant pathogens. We found this experience very encouraging, particularly given the likelihood of similar lockdown conditions being imposed again.

4.2 | Promoting the conservation of plant pathogens

Botanic gardens generally focus on plant conservation, but the conservation of native plant pathogens, as a component of local biodiversity, should also be considered. This point has already been made by Ingram (1999, 2002), and came up again in the context of the IYPH2020 (Ingram, 2020), through three initiatives of the BSPP: (a) the #WildPlantDisease Twitter challenge, in which we participated in late August, by posting some of the pathogen photographs presented in Appendix S1; (b) the Welsh Rust Group, producing red data lists and census catalogues for native plant pathogens in Wales; and (c) the Wyre Forest Study Group, a citizen's science research group studying the natural history of the Wyre Forest in the West Midlands, which has recently decided to survey native plant pathogens. The conservation of plant pathogens essentially occurs ex situ, in microbiological collections, the activities of which are coordinated by the World Federation for Culture Collections (Hawksworth, 1997). Strict biotrophic pathogens, such as rust and powdery mildews, which account for more than half the pathogens described in this article (Appendix S1, Table S1), are obviously more problematic than fungi that can be cultured in axenic conditions. Consequently, the alternative principle of plant pathogen conservation in situ seems to be essential, even though it goes against the intuition of most plant health scientists, whose careers have been dedicated to preventing or eradicating plant diseases, and who have long adopted a normative view of plant health (Döring et al., 2012). This purely normative view no longer seems to be widely supported, at least in Europe. New conceptual frameworks for disease management, such as agroecology, are paving the way for the management of certain diseases by the stimulation of ecological regulation mechanisms, rather than aiming to achieve pathogen eradication sensu lato, through the use of fungicides (field scale), or through the implementation of phytosanitary measures (at the scale of national territories). The conservation of plant pathogens can benefit from the naturalist dimension and can be appreciated for its educational and artistic value. In a context in which considerable means are legitimately devoted to limiting the emergence of certain pathogens, or eradicating them from vast territories (e.g., *Puccinia graminis* on its alternate host; Zhao et al., 2016), Ingram's proposal (1998, 2002) merits further development: the in situ conservation of pathogens of the wild relatives of crop plants is desirable, not only in the centres of origin and diversity for these crops, to facilitate their management in the long term, but also in the gardens of amateurs, for purposes at the interface between science, art, and education. For instance, it might be possible to imagine a "rust garden", consisting of endemic host plants (main and alternate hosts to promote the completion of biological cycles), in which one waits each year for the plants to become covered with orange pustules, just as one might wait for a rose to bloom in a conventional garden. Such an idea was first proposed by Browning (1974) and Dinoor and Eshed (1990), who referred to "living gene parks" and "genetic reserves", respectively. Of course, before such areas could be established, it would be necessary to characterize the risk for adjacent agroecosystems, applying the strict rule that the plant pathogens conserved should be restricted to those already present in an area. Academics and professionals, through national and international plant pathology societies (e.g., BSPP in UK and SFP in France) for example, could play a more significant role in coordinating and funding the efforts of amateur microbial systematists. The IYPH2020 acted as a catalyst for fostering collaboration, but this would probably not be sufficient. Innovative strategies should be developed, combining substantive issues placed firmly on the agenda of (supra)national institutions and individual initiatives based on agile but mature communication platforms. It should also be noted that certain specific national contexts, such as the ban on the use of synthetic phytosanitary products in French public urban areas since 2017, provide good opportunities for rediscovering urban plants and the pathogens that infect them, in addition to those present in parks and private gardens.

4.3 | Adapting the communication of descriptions of plant pathogens in tune with the times

During the first half of the 20th century, outputs equivalent to our phytopathological strolls (in French, *excursions phytopathologiques*) were published in specialized journals (e.g., Massenot, 1953). They were generally quite arduous to read, as they targeted specialists, lacked illustrations, and did not always include microscopic observations. In the second half of the 20th century, such publications were gradually replaced by systematic studies focusing on more or less restricted types of pathogens (e.g., Gäumann, 1959; Guyot, 1938, 1951, 1957), or geographical areas, such as regions (Kuhnholtz-Lordat & Blanchet, 1948) or countries (Savulescu, 1953; Viennot-Bourgin, 1949), but these studies were still driven by a naturalist descriptive purpose. Such phytopathological descriptions have not completely disappeared (Scheuer, 2012), but they are now much less frequent and are more difficult to publish, as they do not correspond to modern scientific objectives and epistemological standards. Since the beginning of the 21st century, the few reference works that continue to be published (e.g., Klenke & Scholler, 2015) have been supplemented by citizen science, through individual websites (e.g., Ellis, 2020; Kruse, 2020; Lechat, 2020; Sothmann, 2020) or collective initiatives (nature platforms for the sharing of observational data about global biodiversity; e.g., Waarneming.nl, 2021). These initiatives make their content accessible to a broad public and, above all, involve that public as an active player in content development. National and international societies for plant pathology, such as BSPP and SFP, would benefit from linking academic and citizen science.

4.4 | Can we draw lessons from the "Pokémon paradox" to develop an education strategy for plant pathology?

Generally speaking, the scientific curiosity of the public, and that of young children in particular, in a naturalist context, can and should be stimulated. The COVID-19 lockdowns, as shown by our experience described here, highlighted that simple actions promoting knowledge about plant pathogens can be attractive. Twitter has become an arena in which expert plant pathologists, professionals, and the general public can exchange. More surprisingly, drawing a parallel with the social phenomenon "Pokémon mania", can also provide inspiration for attracting an even wider audience, beyond the experts and amateurs already interested in plant pathogens. Pokémon is a turn-based role-playing game in which the user captures various species and uses them to fight other characters. This game was originally created in 1996 by Satoshi Tajiri, an amateur entomologist, and was partly inspired by his love of nature and his enjoyment of collecting insects. Several years later, zoologists established that British children were better at recognizing imaginary creatures from Pokémon than they were at recognizing local wild animals, and concluded, somewhat provocatively, that "conservationists are doing less well than the creators of Pokémon at inspiring interest in their subject" (Balmford et al., 2002). Acorn (2009) even referred to the "Pokémon paradox", stating that this game is "both the antithesis of natural history education, and an inspiration to budding naturalists". This paradox could be relevant for other organisms, such as plant pathogens, even though these organisms are much less popular and attractive to the general public than insects. One might think that this paradox increased in 2016 when Pokémon GO, the augmented reality mobile game developed by the company Niantic, brought the initial game into the urban world of video games, but this would be without taking into account the fact that this game required walking outside, usually in urban areas, to capture the virtual creatures. Finally, the players of this game have many points in common with those who, like us, looked for plant pathogens in 2020 under lockdown constraints: more time on screens and social media (Qin et al., 2020), walks in spatially limited areas, including green open spaces and forests. Some organizations, such as the Royal Horticultural Society in the UK, have organized Pokémon-type tours, to help the public to discover gardens (Kondonis, 2016). Going beyond its frivolous nature, Pokémon-style approaches provide a good opportunity for science educators, and not just entomologists, to increase the interest of children in their natural environment (Dorward et al., 2017; Schmidt-Jeffris & Nelson, 2018). The creatures they find can "metamorphose" like insects, but fungal pathogens can do this too, with their anamorph and teleomorph stages, corresponding to changes in morphology in response to environmental stresses (e.g., pycnidiospores, blastospores, and chlamydospores in *Zymoseptoria tritici*; Quaedvlieg et al., 2013; Francisco et al., 2019), and they can even go so far as to have five stages, 0 (pycnial), I (aecial), II (uredinial), III (telial), and IV (basidial)—more than any Pokémon species—in the case of heteroecious macrocyclic rusts completing their life cycle on different host plants (Zhao et al., 2016). We are convinced that both biological bizarreness and biological complexity are attractive. The search for the teleomorph phase (sometimes unknown) or for the alternate host has obsessed several generations of plant pathologists and has occasionally led to the publication of emblematic treatises, book reviews, or lifetime methodological works (e.g., Anikster, 1986; Savulescu, 1953). Some alternate hosts took a very long time to be discovered (e.g., the "century-old mystery of *Puccinia striiformis*" elucidated in 2010 by Jin et al.) and the consensus decision to use only one name ("one fungus, one name") was agreed only a decade ago (Wingfield et al., 2012).

4.5 | Conclusion

It is crucial that professional plant pathologists, individually and collectively, play an active part in promoting a favourable perception of plant pathology among the public and in ensuring that relevant issues are taught in exciting and innovative ways in colleges and universities. The experience related in this article paves the way for potentially popular additional actions for communicating about plant diseases and making plant pathology more attractive to the general public, through more direct interactions. The goal is definitely not to focus on the acquisition of specialized knowledge or cutting-edge discoveries, but to share what already exists and to prove that anybody can discover these things in their immediate environment. We highlight the possibility of improving communication about plant pathogens by considering the identification of plant pathogens as a detective game, by adding jokes to descriptions (e.g., comparing aecidial cups with *churros* or with the head of Bart and Lisa Simpson; Appendix S2, conversation D), and finally by activating the addictiveness of a collection approach resembling that used in Pokémon GO. The role of Twitter as a tool for communicating and teaching is well established (Lopez-Franco & Hennen, 1990), but plant pathologists could make better use of this tool. For instance, opportunistic biodiversity observations published through Twitter represent a promising and, until now, unexplored example of data mining (Daume & Galaz, 2016). Furthermore, in 2020, Twitter played a fundamental role in enabling real-time global communication between scientists during the COVID-19 pandemic, at an unprecedented scale (e.g., Pollett & Rivers, 2020). It also made it possible to exchange knowledge and to disseminate scientific education in completely different fields, such as horticulture (Stafne, 2020) and sustainable soil management (Mills et al., 2019). There is no reason why plant pathology could not play a part in this new trend.

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DATA AVAILABILITY STATEMENT

The data that support this study are available in Appendix S1 and Table S1.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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