

From the classroom to the farm: a lesson plan that promotes smallholder farmers' education and training about plant pathology in the context of climate change

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ABSTRACT Climate change represents one of the biggest threats to agricultural productivity around the world. In the tropics, extreme climate and pest and disease outbreaks represent one of the biggest climate change threats to smallholder farmers. Understanding smallholder farmers' educational needs and increasing access to information and awareness of climate change through education and training are key first steps to enhance the adaptive capacity of smallholder farmers. In a primary effort to increase accessible training and education to these communities, we developed a plant pathology lesson plan. The lesson plan introduces basic concepts in plant pathology and disease management using diverse educational activities focused on experiential and collaborative learning. This lesson plan may have implications in enhancing farmers' adaptive capacity and increasing accessible education to underrepresented farming communities around the world.

KEYWORDS climate change, outreach education, smallholder farmers, plant pathology

In the agricultural sector, smallholder farmers, particularly those whose main income centers on agricultural production, are the most vulnerable and affected by climate change (1–4). Increase in temperature and CO₂ can negatively impact agricultural productivity leading to significant yield loss in these systems (5–19). Across the tropics, extreme weather events are increasingly accompanied by pest and disease outbreaks (20–30). Moreover, in many cases, existing or historic approaches for the control of these phytopathogens are no longer reliable (31). For instance, increase in temperatures can alter the degradation and mode of action of traditional chemical control, increasing pesticide resistance (32, 33). This is the case of azoxystrobin resistance in *Phytophthora infestans*, where temperature variations lead to phenotypic and genotypic variations driving azoxystrobin resistance in the pathogen (31, 33). On the other hand, extreme variation in temperature and rainfall can favor symptom development and increase pathogen populations, promoting and exacerbating disease development (20, 33, 34). Although the extent of extreme weather events and pest and disease outbreaks had not been extensively quantified in Puerto Rico, modeling studies suggest an increased exposure and sensitivity to diseases and pests as temperatures rise (22). Similarly, population genomic analyses of *Macrophomina phaseolina* conducted in the United States, Puerto Rico, and Colombia showed the contributions of climate to the pathogen's genetic variation that can contribute to the pathogen's adaptive capacity (35).

Smallholder farms, including those in Puerto Rico, have limited access to financial support, training, or high-end technology, becoming one of the most vulnerable communities when faced with these climate change challenges (3, 17, 36, 37). To accompany this, the global inflation and economic crisis in Puerto Rico have impacted farmers by increasing prices in most traditional agricultural products and reducing

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farmer’s assistance by government institutions. Due to this, farmers must find environmentally sustainable and efficient ways to control diseases and pests that can also save them money, time, labor, and depend less on government or outside assistance. Understanding the fundamentals of plant pathology will help farmers adapt their agricultural practices toward more efficient ones, given this climate change scenario while reducing the economic waste due to incorrect management and control practices.

To help fill this gap of knowledge, we developed “From the classroom to the farm,” a plant pathology lesson plan for smallholder farmers regarding the control of pests and pathogens under a rapidly warming climate. We divided the development into two phases (Fig. 1). In phase 1, we assessed the needs of smallholder farmers in Puerto Rico, with a focus on the impacts and control of pests and pathogens. In phase 2, we used the information from phase 1 to develop and design the lesson plan. Here, we describe the components of the lesson plan and provide open access to all educational materials.

PROCEDURE

A short survey was used to gather information from smallholder farmers in Puerto Rico about the main problems faced in their farms (IRB number: 2103612922). The survey consisted of 15 questions, including 12 multiple-choice questions (one “select all that apply”) and 3 short answer entries. The questions addressed demographics, main problems faced in the farm and crops produced, losses due to pest/pathogens, diagnosing procedures, knowledge about a local plant diagnostic lab and desire for one, and educational interest for topics in plant pathology and control practices (Appendix 1). The survey was circulated to the Department of Agriculture of Puerto Rico and Extension

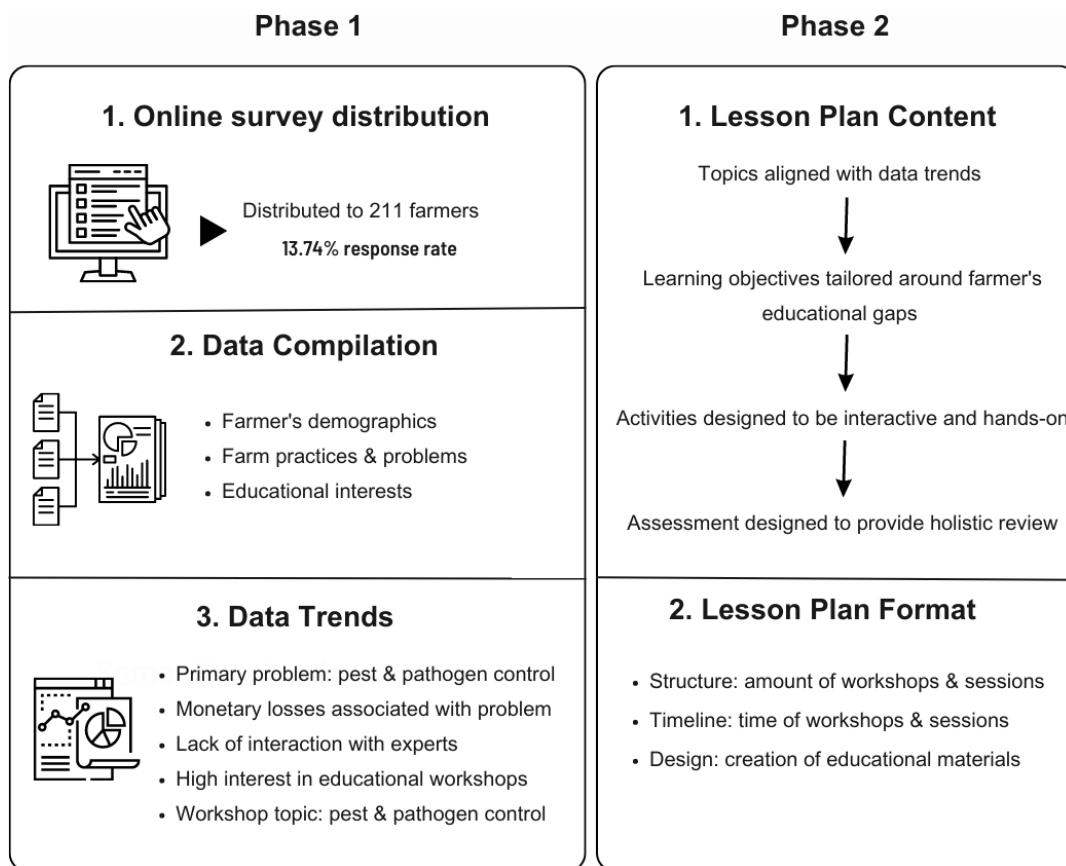


FIG 1 Schematic for lesson plan design. Phase 1, the creation and distribution of an online survey to assess the needs of smallholder farmers in Puerto Rico regarding the control and management of pests and pathogens in the field. Phase 2, the development process of a lesson plan for Puerto Rican farmers and interested institutions based on data collected on the survey.

TABLE 1 Content, timeline, and activities associated with each workshop

Content	Workshop	Session	Timeline	Activity
Introduction to plant pathology	1	1	40 min ^a	K-W-L chart
Signs and symptoms of plant disease		2	1 h ^a	Activity #1
Factors causing disease in plants		3	1 h	No activity
Diseases in tropical vegetables	2	1	40 min ^a	No activity
Diseases in tropical fruits		2	1 h 10 min	Activity #2
Control practices	3	1	2 hr	Activity #3

^aA 10-min break between that session and the next.

agents in Puerto Rico via email, and distributed to a total of 211 farmers, in Spanish. A total of 29 farmers completed the survey. One individual was dropped from further analysis as the individual left approximately half of the survey incomplete. Responses were kept anonymous and recorded digitally through Google Forms (Appendix 2). Survey results demonstrated the control of pests and pathogens as the primary problem faced by farmers. Survey captured the cultivation of 37 crops classified into 5 broad categories to simplify crop classification: vegetables, fruits, beans, herbs, and others. Of the five categories, vegetables were most frequently produced by farmers with a primary focus on sweet potatoes and cassava, followed by fruits with a primary focus on bell peppers and plantains. Out of the 28 farmers, 67.7% of individuals reported experiencing monetary losses due to pests and pathogens, ranging from \$1,000 to \$5,000 (88.9% of farmers) or from \$5,000 to \$10,000 (9.4% of farmers) annually (1.8% provided no answer). In addition, the survey showed a limited knowledge of, or history of interacting with, Extension agents (85.4% of individuals indicated diagnosing diseases themselves; 83.1% reported not knowing of a reference laboratory). Because many farmers in Puerto Rico are not formally trained in agricultural sciences (Miguel García Carrucini, personal communication, 2023), there is an increased number of incorrect diagnoses and a growing confusion about management leading to monetary losses. These results shaped the focus and concepts included in this lesson plan. The lesson plan centers on seven learning objectives and was designed to be completed in three workshops: Foundations of plant pathology, Disease in tropical crops with a focus on vegetables and fruits, and Integrated and sustainable control practices (Appendix 3). Each workshop is divided into sessions that contain a detailed lesson plan, activities, assessments, and theoretical framework behind them (38–109) (Appendices 4 to 6). A table detailing the content, timeline, and activities associated with each workshop can be found in Table 1.

CONCLUSION

In the absence of mitigation strategies for climate change, the agricultural sector is faced with dire impacts in the production of food and sustenance, increasing food insecurity. Within this sector, smallholder farmers, responsible of producing 70%–80% of the world's food supply, are especially vulnerable (110, 111). The resulting lesson plan aims to improve comprehension of plant pathology and related concepts in smallholder farmers and create a vital resource that can be used to provide access to training and education. Through this lesson plan, we aim to enhance smallholder farmers' knowledge and adaptive capacity, increase accessible education for underrepresented farming communities, and provide Extension agents and institutions with open access to educational materials. To extend its impact for diverse learners across the US, Latin America, and beyond, we are incorporating a template of Spanish and English language (Appendix 7). For future directions and potential adaptations, see Appendices 8 and 9 (112–115).

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Conceived of study, N.C.C.; Distributed survey, N.C.C.; Collect and analyze data, N.C.C.; Develop a lesson plan, N.C.C.; Reviewed lesson plan, S.M.G.

An Institutional Review Board responsible for human subject's research at The University of Arizona reviewed this research project and found it to be acceptable, according to applicable state and federal regulations and University policies designed to protect the rights and welfare of participants in research. IRB number: 2103612922. The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

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AUTHOR CONTRIBUTIONS

Sofía Macchiavelli Girón, Validation, Writing – review and editing.

ADDITIONAL FILES

The following material is available [online](#).

Supplemental Material

Supplemental appendices (jmbe00090-23- S0001.docx). Appendices 1 to 9.

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