

Harnessing The Potential of Open-Source Database Platform and Related Web Technologies for Managing Seed Inventory of Cereals Germplasm Collection

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Philippine Cereals Genetic Resources Information Database (PCGRID) exemplifies that industry-class germplasm documentation and inventory system can be developed and implemented using open-source database system platforms and web technologies such as PostgreSQL and the Yii framework. These open-source resources perform well with off-the-shelf retail consumer market hardware configurations and commercial domain hosting and cloud services. The PCGRID has shown that rapid access, better-quality information, effective data filtration; improved data integrity and streamlined and integrated data management is a better forward option for seed inventory management and germplasm documentation, in general. Online implementation and administration further improve functionality and value of the system. Data can be accessed and retrieved, appended, and reviewed anytime, anywhere where internet services are available. Online administration, however, involve operational costs such as subscription to services providers or as additional server load to the institution's in-house systems facilities or acquisition and installation of hardware systems and internet subscription. Moreover, a dedicated systems administrator is necessary for keeping the database system updated, continuing systems design and features improvement, and to rectify bugs and crashes.

Keywords: Germplasm conservation, germplasm database, germplasm seed inventory, online, PGR documentation, postgresql, SQL, Yii framework

INTRODUCTION

Crop genetic resources have been since fundamentally important to improving crop agriculture productivity in various aspects such as increasing yields, increasing resistance and tolerance to biotic and abiotic stresses, improving consumption characteristics favoring consumer preferences and other agriculturally important traits. The benefits derived from genetic resources conservation and use were estimated in 1999 to be about USD 336M expressed as welfare improvement for consumers (Heimlich 2003). The value of crop genetic resources may be summarized in the following categories: direct use, indirect use, option value, quasi-option value, bequest value, and existence value (Heimlich 2003). It is predicted that demand for plant crop genetic resources will continue to increase in the future to feed the ever-increasing global population (Salgotra and Chauhan 2023).

Cognizant of the importance of these valuable biological resources, its conservation has received significant attention. The conventional approach to the conservation of germplasm of orthodox seed types is through *ex situ* conservation by genebanks (Jaramillo and Baena 2007). Germplasm seedlots are primarily stored through low seed moisture content and low temperature strategy. The *ex-situ* conservation entails a set of operational procedures for effective and efficient handling of germplasm materials (Rao et al. 2006). These procedures generate various sets of technical and operational data which may be categorized as technical accession data and inventory

management data. Collection registration data is a summary of the identity circumstances of the accession. This is directly associated with inventory management data sets such as regeneration, storage, viability monitoring, seed stock monitoring, seed withdrawals and distribution.

Managing seed inventory of *ex situ* germplasm collection is a challenging activity. Accession identity data must run consistently with regeneration, storage information, seed stocks, withdrawals, viability monitoring seed requests and distributions. Because these data-generating genebanking process points are interlocking, poor data congruency among identity data and inventory management data, could end up in poor information quality on seed availability and viability status. For example, any seed withdrawal made should immediately reflect the available inventory balance; seedlots of a given accession needs to be specifically identified as each seedlot may have different viability status and regeneration data; new seed stocks deposit should be immediately reflected in the inventory total for the accession; viability and/or stocks status should prompt for priority listing for immediate regeneration, and similar other situations. However, tracking and relating these data sets are particularly taxing when data are manually handled since management of relevant information is not generated in real-time. Wiese et al. (2020) noted that about 35% of genebanks surveyed still rely on manual data management while 60% rely on spreadsheet office applications.

Hence, digital technology-based solutions may offer an interesting alternative to address the downside of manual data management in genebanking. Some of these computational data management resources and web-based technologies are even made available as open-source resources. Among the popular open-source industry class database management system platforms are MySQL, PostgreSQL, MariaDB, MongoDB, SQLite, CockroachDB, Redis, CouchDB, Neo4j, FirebirdSQL, OrientDB and Cassandra (Fivetran.com 2023). These relational database platforms suit the commonly tabular form of datasets in most genebank operations in which each row corresponds to the string of data for a given accession. Examples of digital databases for germplasm data have been presented. These however were focused on the handling of technical accessions data such as phenotypic characterization, evaluation and genotypic or genomic data (Noorzuraini et al. 2020; Devraj and Prata, 2016; Lee et al. 2005; Praveen et al. 2015; Sanderson et al. 2021).

In seed germplasm conservation, managing seed inventory is a multi-activity process which requires attention to accession identity and seed inventory issues such as stock availability, seed lot viability, seed requests and withdrawals, among others. Unlike technical germplasm data which are standalone and static, inventory management data are inter-related and dynamic. Thus, an event in one process should reflect the result on the other, trigger an initial action on the other or be cross-referenced with other records. The integration of process flow is essential in keeping seed inventory status updated. However, this is quite a task when handling inventory data manually. It is often an overlooked aspect of record management and documentation in many germplasm banks.

Therefore, a responsive system of inventory data management capable of reflecting real-time information can improve record management efficiency and information quality while also reducing chances of errors. Consequently, it may improve operational efficiency. Further, utility value of a germplasm database system can be enhanced through implementing it as web-based providing near continuous access to users. Several open-source web technologies are also available. The Yii framework is one of the early web application frameworks made available and still currently in use (www.yiiframework.com).

The University of the Philippines Los Banos (UPLB) holds about 4000 accessions of cereal crops germplasm which includes corn, rice, sorghum, teosinte, millet and adlay. Currently, datasets across activities are summarized in spreadsheet application files from their original hardcopy data sheets and forms. Thus, this project was undertaken to develop an initial iteration of germplasm database system with emphasis on managing seed inventories using open-source database system platform and web-technology resources. It further aims, in particular, to assess the suitability of PostgreSQL and the Yii framework for use in germplasm data and seed inventory management for the collection.



Figure 1. Inventory management and technical accession data sets commonly collected and generated in for cereals germplasm conservation

METHODOLOGY

Operational walk-through and systems analysis

Data generation was observed and identified through a walk-through of the processes flow. Data sets gathered and/or variable points were collected and recorded. Data types and values were identified and categorized. The walk-through included observation and orientation on how the main operational procedures in *ex situ* germplasm conservation activities are conducted such as, collecting/acquisition, seed increase/regeneration, characterization, evaluation, storage, withdrawals, seed quality monitoring, seed requests and distributions.

From the gathered observations and data sets, database design structure was drafted for construction. The design and structure of tables, relationships, queries, and outputs were coded in the PostgreSQL. Initial testing was conducted for the constructed database for data entry, data validation and output. Errors, bugs and other technical issues discovered along the testing process were fixed. For web implementation the front-end was constructed using the Yii HTML framework. Both technologies used were open source. System application development was done as an offline activity. Upon initial testing of the web interface, the database system application was hosted online through a subscription on a commercial domain registry and storage VPN services provider. Actual data available was then migrated to the database.

Access, acquisition and installation of database system platform and web framework technologies.

The SQL platform was accessed and downloaded from its home site, postgresql.org. For front-end development the Yii framework was downloaded from its homepage, yiiframework.com. The database and web technologies were installed in an x86-based 64bit Intel Core i5 laptop pc running on Windows 10 operating system. Additional hardware configurations are as follows: 8Gb DDR4 2666Mhz memory, 128Gb SSD, 1Tb 5400rpm hard drive, 4Gb GTX1050 video card and 15.6 FHD display. The download, installation and execution processes ran normal on the hardware configuration. There were no software and/or

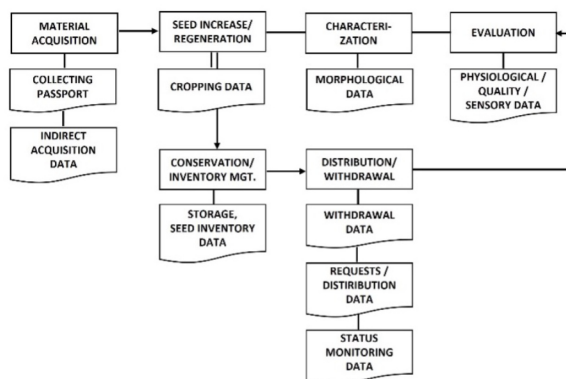


Figure 2a. Diagram of activities in cereals germplasm conservation and respective set of data generated.

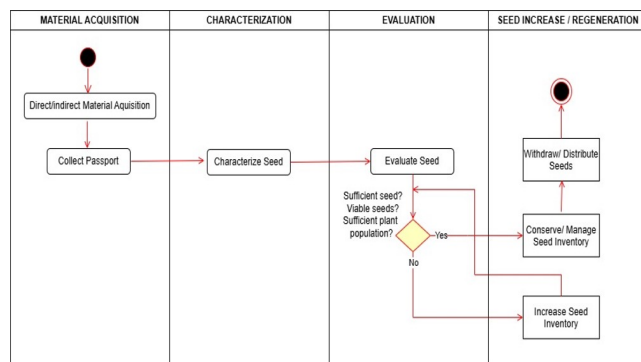


Figure 2b. UML activity diagram of handling cereals germplasm material from sample acquisition to accession distribution.

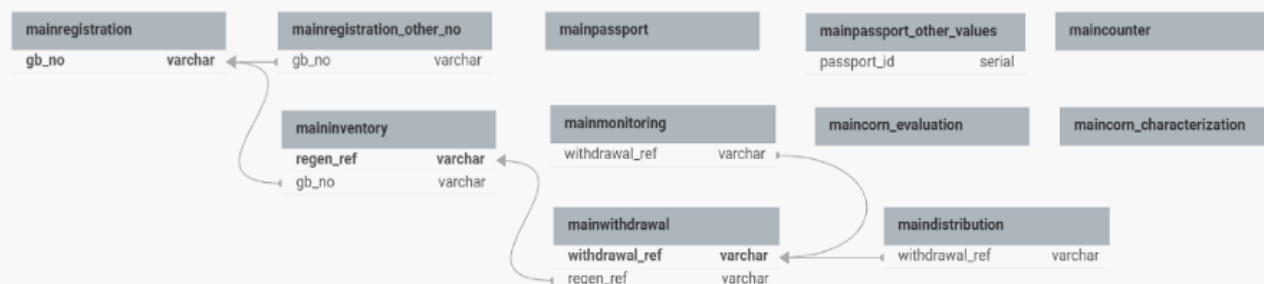


Figure 2c. Simplified ERD of the PCGRID database system.

hardware compatibility issues that were encountered during the process. The database system application development was executed well and no technical system issues encountered. Similarly, the framework design for the front-end web implementation of the database system application was compatible with the Yii framework.

RESULTS

Tables, data types and systems organization

A walk-through over the operational procedures identified the activities which generate three categories of data sets: (1) crop generic technical static data sets which included registration and passport, (2) crop specific static technical data sets which include characterization, evaluation, and (3) seed inventory management data set which included seed regeneration and storage, seed withdrawal, seed monitoring, seed request and distribution (Figure 1). Data points equivalent to field columns ranged from 8 to 90 composed of data types such as numbers, formatted alphanumerical, free text format, date and value list. Figure 2a shows the activity flow and sets of data generated under each activity. Figure 2b shows the UML activity diagram that traces the handling and conservation route of a cereal germplasm material from acquisition to distribution. Figure 2c shows the simplified entity-relationship diagram (ERD) of the PCGRID database. From the above information, the systems design was developed and implemented. The database system developed is called PCGRID (Philippine Cereals Genetic Resources Information

Database). Results presented below focuses on the accession management such as the registration and inventory related tables.

Except for Registration, the rest of the data sets have recurring records, occurring multiple times for a given accession. Accession management records are generated by the occurrence of an event of the given activity. For instance, the regeneration record of an accession is generated for each cycle of regeneration. This also is true with storage, seed withdrawal, distribution, monitoring and germplasm requests. No unique record is common among the data sets, except for the germplasm registration number (formatted as GB0) under the Registration table. Thus, the inventory management tables have separate unique primary keys from each other with one common field, the GB number.

Structure, information management features and functionalities

As identified above, the seed inventory management database consisted of the following tables: Registration, Inventory, Withdrawal, Monitoring and Distribution (Figure 3). A derived table, Inventory Summary, was added in the design to summarize the total inventory record for each registered accession. This table gives the sum total of seed currently available, all storage locations and number of regeneration cycles.

In practice, germplasm registration is an action to acknowledge receipt of a germplasm material from a source, hence some materials, such as those of

Figure 3. Inventory related table tabs of the database management system application

Figure 4. Error alert when adding a new Inventory record with invalid Registration record

Figure 5. Automatically created Distribution records upon creation of Withdrawal record

random donations may or may not have passport data or sufficient information. The design requires that a valid Registration record should exist before other records, particularly seed inventory management records, can be added, i.e., an inventory record can only be added if the accession has been registered. Additionally, seed withdrawal records can only be added if a corresponding inventory record exists. Figure 4 shows an error alert when trying to add an inventory record without an existing registration record. Since an accession can have multiple events of seed regeneration, inventories are recorded by regeneration cycle. The system designates each lot with a *regeneration reference number* serving as the table's primary key. Withdrawal, Distribution and Monitoring records are indexed separately by a unique key for each table.

For every seed withdrawal event added, the system automatically generates an initial record of either seed monitoring or seed distribution which can be updated at a later time. This feature ensures that each seed

Figure 6. Summary Inventory table showing highlighted accessions with low seed stocks

Figure 7. Summary Inventory table showing regeneration reference numbers for each accession

withdrawal is immediately recorded and therefore reflects a real-time amount of seed stock. The initial record generated is stored in the particular table corresponding to the purpose of seed withdrawal. If the purpose is for viability testing or regeneration the record is created in the Monitoring table. While, if the reason is for distribution, the record is created in the Distribution table (Figure 5). The initial records can be updated at a later time to include other details such as the result of viability test conducted or the details of germplasm requests. Since a seedlot can have multiple events of withdrawal, monitoring and distribution, the tables have separate and unique keys reflecting, for instance, the number of times seed withdrawals have been made from a seedlot or how many times the accession has been distributed. The Withdrawn amount is automatically debited from the total of the specific seedlot to reflect the current seed quantity. As a stock inventory monitoring feature, the system sends alert by highlighting the row when the total seed inventory balance per lot and/or the total hit the set minimum value (Figure 6). Highlighted accessions indicate priority for seed regeneration in the soonest schedule possible and therefore may not be available for general seed distribution. The Inventory Summary table also lists all regeneration numbers of an accession, thus showing which accessions have been planted multiple times and which accessions have not been planted since their initial seed increase (Figure 7). The design also integrates the basic database system functionalities – *add, view/edit, delete* and *output*. Export and import functions were also integrated for large file transfer to and from a common spreadsheet format, Microsoft Excel. The Query or search function was designed to execute a simple one field value filter, combination of

PCGRID										
Showing 1-14 of 14 items.										
#	Regen Ref	Go No	PHL No	CGUARD No	Crop	Crop Group	Date Stored	Total Seed Weight Active	Store Code Active	Total Seed Wt
1	R2020-034	0808951	PHL34823	CGUARD2015-0169	Com	Cereals		122.84	214CE	(not set)
2	R2020-0140	0807024	PHL34227	CGUARD2015-0242	Com	Cereals		129.64	214CE	(not set)
3	R2020-029	0808428		CGUARD2017-0708	Com	Cereals		107.12	215CE	(not set)
4	R2020-078	0870195		CGUARD2020-1010	Com	Cereals		180.6	218CE	(not set)
5	R2020-091	0870196		CGUARD2020-1020	Com	Cereals		167.05	218CE	(not set)

Figure 8. A query output using the combination of regeneration reference, crop and range of total seed weight as filters.

fields, point value or range of values for integer fields (Figure 8). When adding a new record or modifying an existing record, data is saved in real-time though the save button can be activated to ensure that all works are saved prior to leaving the page or the application. Data sets can be backed-up by exporting into a common PC spreadsheet format.

Front-end and user's interface, implementation and use

The database management system is implemented as a browser-based application using the Yii framework as the html protocol. Offline testing was generally stable with initial bugs and errors discovered consequently rectified. The database system was eventually deployed online by subscribing to a commercial domain registry and cloud storage services provider. The general systems architecture is illustrated in Figure 9. Online operation is generally smooth and stable with a few minor bugs found along the course of testing and use. The database system requires minimum hardware configuration and can be accessed on both the Windows and Mac operating environment. Homepage at log-in is shown in Figure 10. The system, however, requires stable and relatively fast internet speed as data accessing adds up, especially when adding or editing records in related tables. Accession management tables are universally designed for most crops germplasm stored as seed. Available data have been migrated to the respective tables. As of date, migrated data included 5200 Registration, 7160 Inventory, 876 Withdrawals 487 Monitoring /Regeneration and 219 Distribution/Seed Requests records. The Inventory Summary lists a total of 3911 records.

DISCUSSION

PCGRID is among the few attempts among local germplasm banks to organize a digital Plant Genetic Resources (PGR) documentation emphasizing seed inventory tracking utilizing industry class open-source technologies and resources. It is a fully functional database management system application for managing accession registration and inventory management related data sets of the current needs described. It has the key elements, functionalities and features of a general database management system. The system utilized both industry-class sql platform and web framework technology. The application

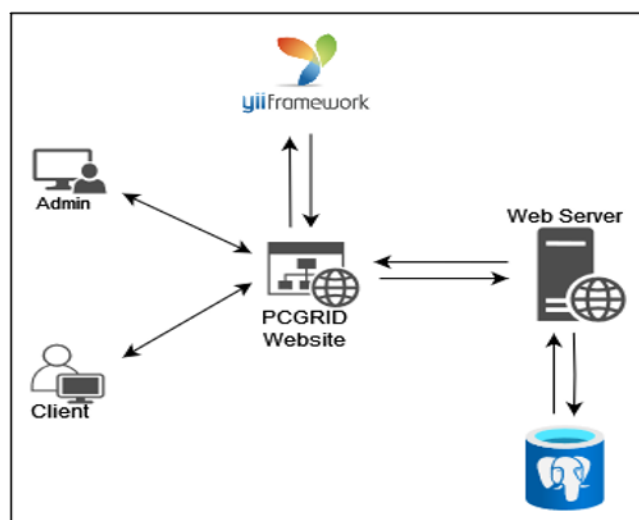


Figure 9. Illustration of the systems architecture of PCGRID

stores, retrieves and runs queries on the uploaded database. It allows for entry, viewing, updating, and deleting data, the basic functionalities of a database management system (Mullins 2024). The project thus exemplifies the ready availability and utility of open-source database solutions and web technologies.

A germplasm bank planning to digitize their germplasm documentation and records management have several open-source solutions and even newer technologies. Moreira de Oliveira et al. have (2014) demonstrated the usability of developing agricultural management information systems using open-source solutions. The usefulness of open-source database management development tools was earlier demonstrated by Villordon et al. (2007) on Kenyan sweet potato germplasm. PostgreSQL has been utilized earlier in crop phenotypic characterization and genomic data in academic and commercial plant breeding by Heckenberger et al. (2008) and on similar data sets in germplasm collection (Lee et al., 2005). Rajagopal et al. (2005) earlier demonstrated the applicability of PostgreSQL in developing a data management system for coconut crop improvement. Ravoof (2024) listed PostgreSQL as the Number 3 top picks among the open-source database management systems. Among the advantages of Postgresql include its being an industry class, scalable performance, functionality, large data volume handling, affordable solution being an open-source, excellent track record of data security and reliability, highly compatible with a range of tools and technologies, easily integration with various applications. supported by third-party tools, languages and extensions and ACID-compliant (Hassan 2022; Shaik 2023). The Yii framework on the other hand, is touted as secure, fast, efficient and flexible yet pragmatic PHP framework technology (yiiframework.com 2024). It is listed among the popular web development frameworks offering advantages like robust security features to protect against common vulnerabilities and simplifies database interactions and SQL queries, among others (Martin 2024). These two software development platforms are easy to use and belong to the top preferred open-sources solutions. Their followers and users serve as a helpful technical



Figure 10. The PCGRID Homepage

support community. As open-source technologies these are readily accessible and publicly available.

Given appropriate systems analysis, a systems design can be executed that mirrors how data are generated and grouped; how the data are related and what type of data are generated in each operational activity of the genebank; and how data can be organized and be used to guide genebank management operations. In this project, it was designed that a prior germplasm registration record exists before an inventory record can exist. This is to ensure that a germplasm material is a recognized acquisition. Seed inventory and withdrawal records are similarly designed to ensure that information on seed stock is available near real-time. Likewise, designing the system to auto-generate the initial record of withdrawal purpose ensures 1-to-1 tracking of all seed withdrawals. With many *ex-situ* genebanks being underfunded, understaffed, and lacking an updated information management system (Taryono et al. 2020; Fu, 2017) it is common that data recording is done manually. Thus, updating records can often be overlooked and, in many cases, often neglected until eventually forgotten. The importance of documentation system design which allows for keeping updated information on the status of seed inventory has been emphasized (Painting et al. 1995). Wiese et al. (2020) discussed the importance of germplasm documentation systems which addresses data and information management relating to storage conditions and location, and the quality and quantity of seeds, among others to enable efficient and effective genebank management. It includes information such as germinability or storage quantity as well as information on health tests that have been carried out or are pending. In the current project, the inventory tracking feature was able to demonstrate the limitations of manual recording systems. It revealed the inconsistencies in the seed regeneration schedules leading to multiple cycles of accessions, while some were left un-regenerated. Additionally, adopting a digital documentation system for a seed germplasm collection reduces redundancy of data fields across forms typical to manual data sheets therefore, streamlining data encoding and cross-referencing. Miliar and co-authors (1982) had emphasized that management of germplasm inventory

data can save considerable time and resources and is more accurate compared to manual ledger type inventory system, allowing rapid response to user's queries. In this system, identity data needed in the inventory table are automatically loaded from the registration by just keying an accession key, the genebank registration number (GB No.).

In manual data handling, it is helpful to adopt at least two accession identity numbering. Manual handwriting is prone to errors, especially when handling large numbers of seedlots or a batch of regeneration set-up. Hence, adopting twin accession ID labeling style may serve as an error-catch, with either of IDs serving to verify the other. This is however an additional layer of manual task across data files. Therefore, adopting an automated recording system streamlines the process by encoding the one of the identification values just once which becomes automatically available on the same field across files. In this project for instance, adding a new withdrawal record requires only to key in the GB No. It then automatically displays the accession number and crop name and lists down the regeneration reference numbers and the storage location(s) specific to the accession. The system-generated information also serves as rapid data verification and validation features, which are not readily doable with manual data handling. Agrawal et al. (2007) concluded that adopting a digital data management system reduces manual data filing work, provides for quick data access and generates fast, well formatted, and customized reports.

Digital management of germplasm inventory data likewise provided improved quality of information in real time. It can be noted that, at a glance, it can be identified which accessions have below the set minimum seed balance or which accessions have been repeatedly regenerated and which accessions are rarely regenerated. Agrawal et al. (2007) noted that this database feature is quite important in properly managing germplasm inventory by providing up-to-date information on stock inventory and viability status. Such information can prove to be a struggle to generate in manual inventory data handling. Additionally, summary statistics can be readily cited, such as inventory totals by a field variable (e.g. crop).

The importance of integrating a function to handle seed conservation status variables into the genebank database management system for effective seed storage and improve seed inventory operations was similarly stressed by Takeya et al. (2013).

But other than the software platform and hardware requirements, there is also the need for a technically adept systems developer and/or database system administrator with full grasp genebank operation particularly the seed inventory management system. Inventory management data are dynamic, recurring and inter-related. That is, an accession can have multiple events of seed multiplication, storage, distribution and monitoring. In contrast, technical accession data is static and independent. Thus, it is logical and necessary that the technical system developer and/or database system administrator works hand-in-hand with the germplasm conservation manager. The importance of enlisting a proficient database system developer and administrator has been emphasized (Khana et al. 2014).

Implementing the system as web-based offers an option for extended accessibility over stand-alone operation. Data can be added or updated, and information can be accessed 24/7 anywhere, where internet services are available at minimum speed requirement. This can be done by operating one's own server or subscribing to a third-party services provider. PCGRID was deployed online through a commercial Virtual Private Server (VPS). Included in the server plan are 40GB storage, 2TB Bandwidth, 2GB Memory, and 3 Cores. iTG Technologies (2023) discussed the pros and cons of subscription-based hosting against in-premises infrastructure installation. The PCGRID hosting subscription option was found to be easy to implement, affordable, and customizable for the current need. Maisha and Astari (2024) added that factors influencing costs of hosting are hosting type, hosting provider, period of plan and features, among others. The subscription service subscribed to in this project was a discounted annualized basic tier plan and can be easily transacted online without the need for special transaction financial accounts.

CONCLUSION

The PCGRID system has shown that a responsive database system with functionalities and features for managing seed germplasm inventory and technical accession data sets can be developed and implemented using open-source database system platforms and web technologies, such as PostgreSQL and the Yii framework. These open-source resources generally run well with common market sourced consumer hardware configuration and hosted on commercial domain hosting services. PCGRID exemplifies that adoption of digital germplasm inventory data management offers rapid and better-quality information relevant to germplasm inventory management. It also demonstrated that data handling, integration and data integrity management are improved and streamlined in a digital solution. Functionality and value of digital platforms can be further upscaled, such as online administration for extended access, given technical support resources

are available. On a broader level, PCGRID likewise reiterated the value of adopting digital data management systems which may not only be for germplasm documentation but also for many other agricultural research data handling.

Moreover, online database management further enhances the utility value of a germplasm inventory management system. Data can be accessed, appended, and reviewed anytime, anywhere where internet services are available. Administration and management of germplasm inventory online, however, involve operational costs which may come in the form of subscription to commercial services providers, or as additional server load to the institution's in-house systems facilities or acquisition and installation costs of hardware and associated systems software. In addition, a dedicated systems administrator is necessary for keeping the database system updated with the current technologies, continuing systems design and features improvement, and handling and rectification of bugs and systems downtimes. Thus, for plant genetic resources conservation and for other agricultural research programs, in general, which generate and handle sizable volumes of data, the database and web technologies herein presented are available open-sources solutions options. Along with the software resources, competently skilled developers and minimum hardware resources, including internet access are equally necessary for application development.

For forward development iterations of the current project the following are suggested: application of digital tools to fast-track data handling and improve data integrity, such as scanners and digital codes; integration of digital image database and, multiple access data administration, among others.

ACKNOWLEDGEMENT

The authors are sincerely grateful to the Bureau of Agricultural Research of the Department of Agriculture for providing the project fund. Likewise, the authors wish to thank the trademark and/or brand owners, associated institutions and support groups for making the technology resources used in the project herein described, available publicly.

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