# Forgotten Foods: A manifesto for the future of the food system?

S.N. Azam-Ali and E. Jahanshiri
Crops For the Future, Cambridge, UK

**Abstract**

**The current global food crisis demonstrates the vulnerability of a global agrifood system that relies on a handful of calorific staple crops grown as industrial monocultures in a few exporting countries to feed nearly 8 billion people. We need to *transform* the agrifood system with diverse, climate-resilient, and nutritious `forgotten' crops, novel cropping systems, and less vulnerable supply chains if it is to meet the needs of 10 billion people on a warming planet without destroying the planetary ecosystems on which we all depend. Diversification requires collective actions underpinned by a scientific evidence base to identify the best climate-resilient, nutritious, and desirable crop species for current and future environments. We present a global knowledge base for underutilised crops, `CropBASE,' developed by Crops For the Future (CFF) that allows end-users to choose the most suitable crop diversification opportunities for their situations, how these alternatives compare with business-as-usual with mainstream crops. We also show how hitherto forgotten crops and underutilised crops can provide livelihood opportunities for farming communities, healthier and more diverse diets for consumers and fewer demands on the natural environment. Diversification options are provided for different crops and agroecological environments and examples are given of how such an approach can transition the global agrifood system from its current reliance on `fossil foods' that rely on fossil fuels at each stage of the value chain to diverse climate-resilient and nutritious `future foods.' We also show how a global knowledge system, such as CropBASE, can underpin the Global Plan of Action for Forgotten Foods proposed in the Global Manifesto for Forgotten Foods (https://www.gfar.net/documents/global-manifesto-forgotten-foods) that was launched in 2021.**

**Keywords**: knowledge systems, underutilised crops, agrobiodiversity, bambara groundnut, hemp, climate resilience, diversification

## INTRODUCTION

Supply chain disruptions, an ongoing pandemic, extreme weather and now a war in Ukraine have exposed faultlines in the global food system that we ignore at our peril. The crisis demands nothing less than a complete transformation of the agrifood system — one that involves diversifying the crops we grow, the way we grow them and how we transport them (Azam-Ali, 2021).

Climate change threatens almost everything when it comes to our food. In 2022, more than 40 per cent of wheat on North America's Great Plains suffered from drought. In China, floods mean wheat yields this year will be among the poorest ever. In May, India registered record temperatures of 49°C. Much of Europe suffered a deadly heatwave. The war in Ukraine is yet another disruption to a vulnerable system. Together, Russia and Ukraine supply 28 per cent of globally traded wheat, 29 per cent of barley, 15 per cent of maize and 75 per cent of the sunflower seeds that account for 11.5 per cent of the vegetable oil market. Russia is also the world's biggest exporter of nitrogen fertiliser, the second of potash and third of phosphorous and a major source of the energy that fuels global agriculture.

Essentially, we now have a "fossil food" system in which a few staple crops grown in a few exporting countries are transported to distant consumers around the world using fossil fuels at each stage from plough to plate. To date, our response has been "business-as-usual" as importing countries scramble to find alternative sources of staple crops such as wheat from Ukraine and Russia. However, to protect their food security, 23 countries, including India, have imposed restrictions on wheat exports and other foodstuffs. More will follow.

Humankind has cultivated around 7,000 plant species as crops. Of these, just three — (wheat, rice and maize) now provide over 60 per cent of the human diet. We use 10 per cent of these crops and 18 per cent of vegetable oils for biofuels — equivalent to the food needs of 1.9 bn people. In 2021 China imported 28 mn tonnes of maize to feed pigs and over 40 per cent of the wheat grown in the EU and 33 per cent in the US was fed to cows. Doubling down on mainstream staples will become an increasingly bad investment. If we are struggling to feed a global population of 7.8 billion people, how can we nourish a predicted 10 bn by 2050 on a hotter planet? In short, we must change from a `fossil food' system into a `future foods' one. This must include climate-resilient and nutritious "forgotten" and hitherto underutilised crops, as well as diverse farming systems that have been displaced by industrial monocultures of energy- and fertiliser-hungry staples. We must also diversify farming systems and include landscapes, urban spaces, common land and even gardens as food sources. Diverse systems provide greater resilience to extreme climates than regimented monocultures as well as potential, novel livelihoods for a new generation of farmers. Finally, we need to embrace food as a source of cultural value, nutrition and even joy — not just a means of sustenance and source of profits. The Global Manifesto on Forgotten Foods, launched in 2021, calls for a plan of action in which forgotten foods, from climate-resilient and nutritious crops can become agents of transformation. For this transformation, we must rediscover local, nutritious, and diverse foods and reduce our addiction to a monotonous diet of uniform, ultraprocessed products that are transported around the world.

Transforming the agrifood system requires vision, investment and farmers as innovation partners, not passive recipients of new technologies. In growing forgotten crops in a changing climate it is they, not us, who are the experts. However, without a state-of-the-art global knowledge base, farmers, investors, consumers, and policy makers have no objective basis for agricultural diversification nor quantitative evidence on what crops to grow, how to grow them, their products, end-uses and markets or returns on investment. Our purpose here is to describe CropBASE, a digital knowledge system for agricultural diversification with underutilised and forgotten crops that is being developed by Crops For the Future (CFF), the global research institution dedicated to the wider adoption of underutilised and forgotten crops for food and non-food uses.

## CROPBASE: A GLOBAL KNOWLEDGE SYSTEM FOR UNDERUTILISED CROPS

### CropBase: database structure

Unlike major crops, information on underutilised species is scarce, fragmentary and, often, anecdotal without supporting published and peer-reviewed evidence. Much knowledge is vernacular (unwritten) and held in the heads of farmers who have continued to grow particular underutilised crops for generations without the benefit of conventional research, advocacy or access to extension services (Azam-Ali, *et al.*, 2023) . Hence, the first step towards developing a global knowledge base for underutilised crops is to collate and organise various forms of quantitative and qualitative information about these crops into a common database . A robust data structure that is not only accessible for all but also facilitates predictive analysis, can streamline the development of computer and mobile decision support systems for underutilised crops (Mohd Nizar *et al.*, 2021). Since 2012, in the absence of an existing system, CFF has been developing CropBASE as the first global knowledge system that focusses specifically on underutilised and forgotten crops. Information on over 2700 crops is now stored at various levels of detail in the CropBASE database. Figure 1 shows the general architecture and data flow for the crop diversification platform that underpins CropBASE.

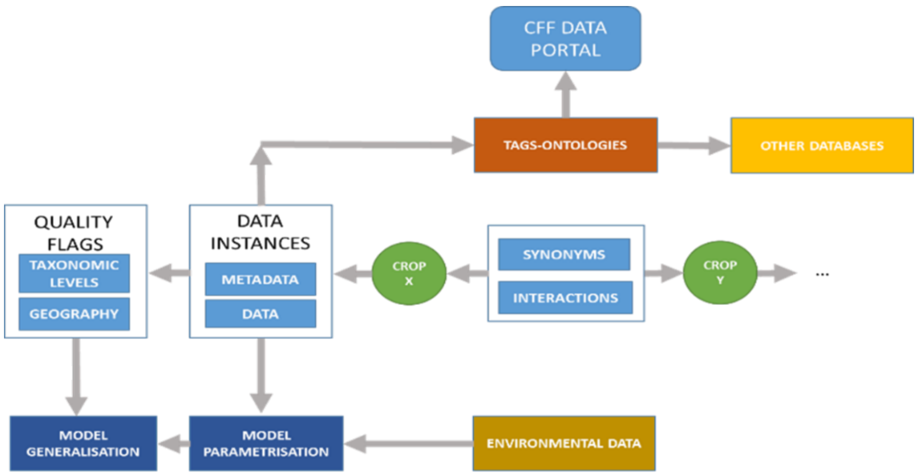


Figure1: Database and system architecture of CropBASE

**CropBASE: data content, definitions, and collection**

Providing an integrated database that is viable for diverse underutilised crops requires the bringing together of data from various stakeholders, scientific disciplines and at diverse geographic scales. Data organised at the species level was collected and organised into the CropBASE database (Gregory *et al.*, 2019; Jahanshiri and Walker, 2015). Data variables used in the development of the database were collected in collaboration with experts in genomics, agronomy and agrometeorology, geology, socioeconomics, and nutrition both within and outside CFF. Several use cases were developed to showcase the benefits of linking data, particularly for underutilised crops. For example Marahaini *et al.*, (2018) describes a holistic view on linking data across all stages with a focus on traceability.

Since much of the knowledge and expertise on underutilised crops is vernacular, a database which stores such qualitative information along with quantitative and published research data would tremendously enhance our understanding of these crops, their properties and uses. Figure 2 show part of the conceptual design for data and metadata storage within CropBASE that includes subject matter information beyond that from published literature and across disciplines. Domain experts were consulted to define standard variables and measurement units across the `research value chain' of these crops.

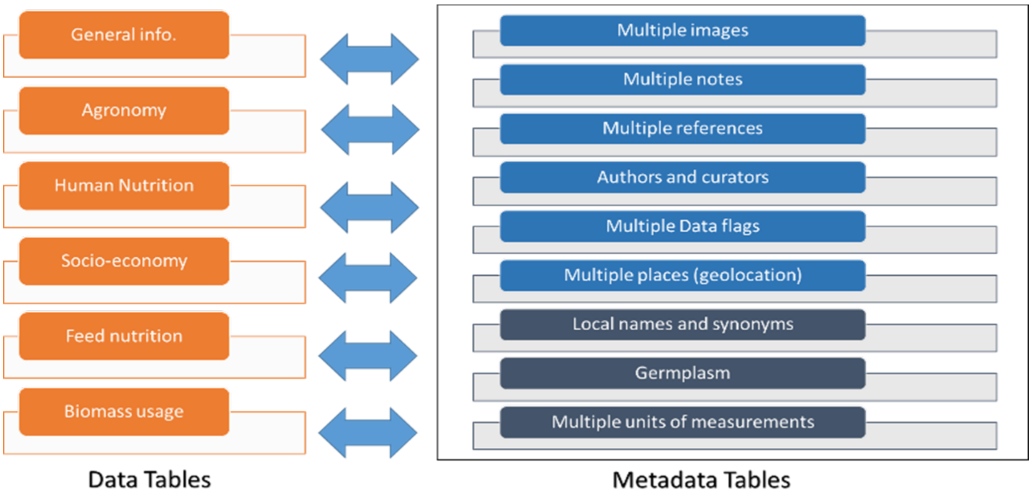


Figure 2: Data and metadata tables across the research value chain of crops.

Different levels of data quality based on location and taxonomic classification were designed for each data instance to fill the data gaps (Figure 3). For each diversification option, the most reliable data that are closest in terms of location, taxonomy and reliability of source are used to screen individual crops. Each data point is assigned a quality flag according to a predefined scale from high quality data found in peer-reviewed publications to data from online resources such as weblogs and observational information.

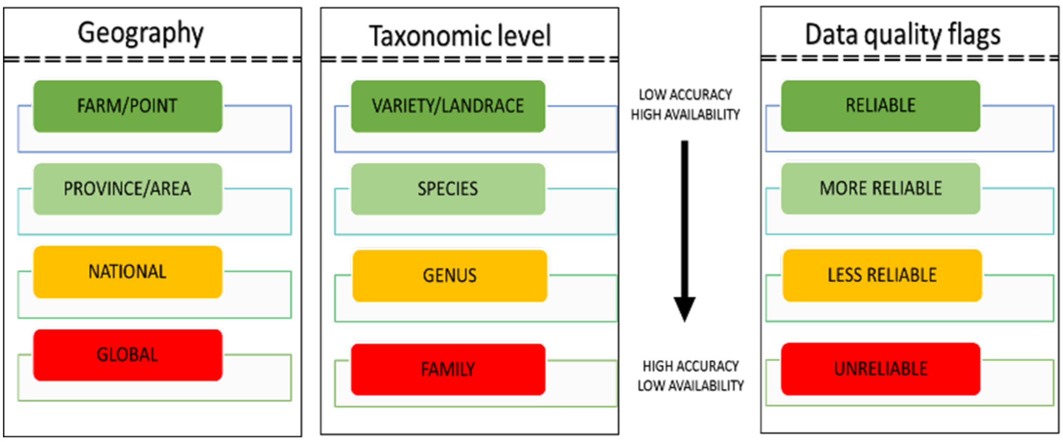


Figure3: Data quality levels within CropBASE

The database taxonomy of CropBASE was mainly built with data from open access literature sources and major plant databases including National Centre for Biotechnology Information Taxonomy (NCBI), Germplasm Resources Information Network (USDA-ARS), Global Biodiversity Information Facility (GBIF), and Encyclopaedia of Life (EOL) for taxonomy and checklists as well as the Food and Agriculture Organisation (FAO) Ecocrop database containing ecological requirements of crops at the species level. Data retrieval was done either by manual data collection following available standard collecting procedures or bulk data transfer into the CropBASE database (Nizar *et al.*, 2021). The core database is hosted permanently on the Google Cloud platform and is freely available at http://cropbase.co.uk.

**SelectCrop: crop diversification tool in CropBASE**

Data that is stored in the CropBASE database provide the basis for a variety of informational and analytical products, one of which is the crop selection tool `SelectCrop'. This selection tool combines crop data with geospatial climate and soil layers to screen crops for any location. Figure 4 shows the suitability tier of SelectCrop that aims to improve livelihood and farming systems opportunities by providing seasonal options for different crops at any specified location. SelectCrop utilises temperature, rainfall and crop soil requirement (FAO, 1976) which are used to create location-based crop climate and soil suitability indices. The detailed algorithm in SelectCrop and its validation are explained in Jahanshiri *et al*. (2020). Since high quality data are not available for all localities, pedoclimatic data at any scale can be used to discern crop suitability that can be used for planning ad hoc (Suhairi *et al*., 2018). To provide an estimate of crop suitability, SelectCrop uses globally available and open access data. However, data quality could pose an issue in this regard as is shown in the case of globally accessible soil data (Wimalasiri *et a*l., 2020). Therefore, wherever possible, it is recommended to use good quality local pedoclimatic data to develop crop shortlisting (Suhairi *et al*., 2022). The system further provides insights on the suitability rank (0-100%) and overall seasonal suitability for growing a particular crop.

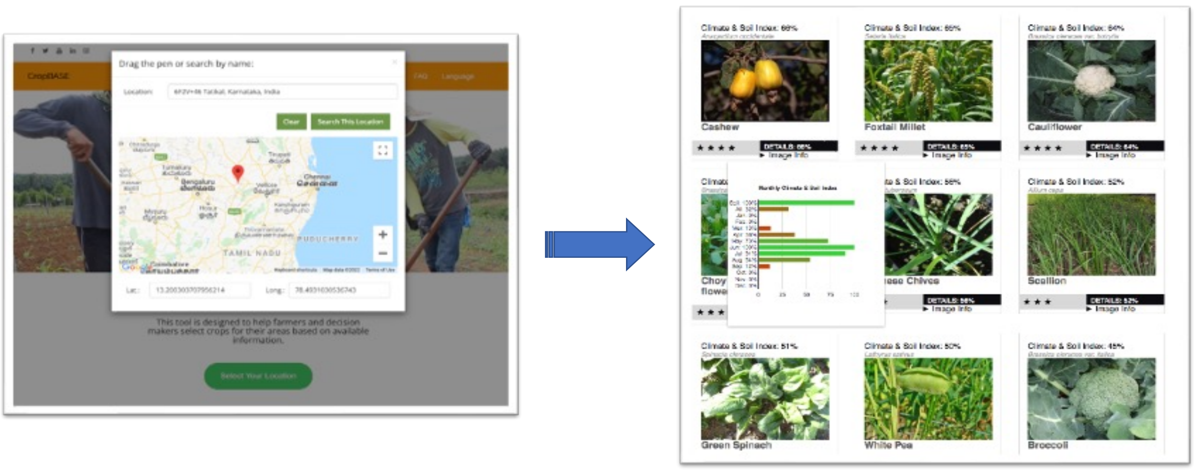


Figure 4: Prototype interface for SelectCrop

**CASE STUDIES**

The purpose of CropBASE is to provide a user-friendly and readily accessible global knowledge base for underutilised and forgotten crops that can be used to evaluate the potential of different crops at any specific location under current and future climate scenarios. End-uses include the suitability, yield, likely returns on investment, climate-resilience and nutritional content of products from specific underutilised crops and comparisons between the performance and uses of different underutilised crops and mainstream crops at the same location. Various tools are currently being developed within CropBASE to provide end-users with the best available evidence on nutritional content (AssessCrop) and agronomic management (UseCrop). Here we present case studies of how the SelectCrop tool has been used to evaluate the potential suitability of underutilised crops under different scenarios.

## Comparing the suitability of maize and bambara groundnut in Malaysia

Despite being in a global megabiodiversity region, Malaysia is a major importer of food and animal feed ingredients and processed products. Many of these ingredients are derived from the import of calorific staple crops such as maize (*Zea mays*) that can be used both for human food and as part of feed formulations for livestock and aquaculture systems. There is potential for Malaysia to grow crops that are suited to its diverse agroecological environments, and which can provide some or all of the carbohydrate, lipid and/or protein fractions derived from imported ingredients. SelectCrop can be used to provide an initial agroecological suitability analysis for a wide array of crops based on their temperature, rainfall, and soil requirements globally. A preliminary analysis using SelectCrop shows that both maize, a mainstream commodity staple, and bambara groundnut (*Vigna subterranea* L. Verdc), an underutilised tropical legume, can be grown within the territory of Malaysia (Figure 5). The annual temperature range across Malaysia shows that almost all of its territorial areas are suitable for both maize and bambara groundnut. However, when we include rainfall and soil requirements, there are clear advantages for bambara groundnut against maize with approximately 50% more land area suitable for the crop based on rainfall alone and over 250% more land suitable based on soil characteristics. Given that both crops typically have seed carbohydrate content of around 65%, there appear to be *a priori* advantages of growing bambara groundnut rather than maize as a source of calories for both human food and animal feed across much of Malaysia especially under changing climates and on marginal soils.

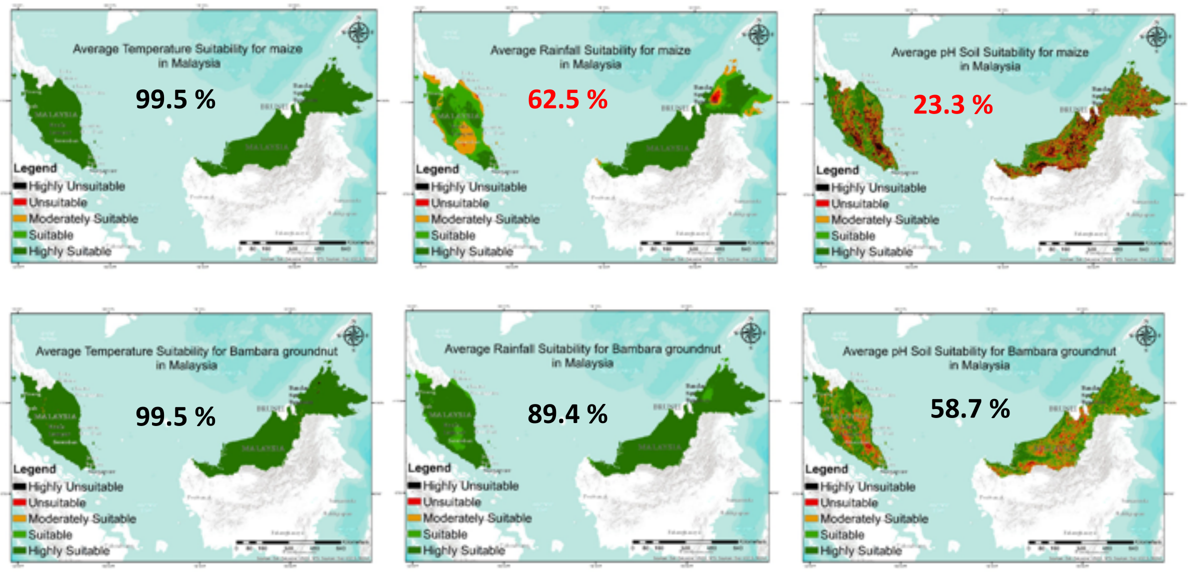


Figure 5: Preliminary suitability comparison for maize (upper panels) and bambara groundnut (lower panels) using available data. Adapted from (Gregory *et al.*, 2019)

## Hemp in Malaysia

Whilst the cultivation of hemp, (*Cannabis sativa L.*), is still illegal in many developing tropical countries, it is a billion-dollar business in many industrialised temperate regions. There is a growing interest in Malaysia to cultivate hemp as an industrial crop both for its seeds and fibre content. However, there is no previous history of growing the crop within the country on a commercial scale. Before advocating its widespread adoption, SelectCrop was used to provide an evidence base for the potential of hemp as crop for commercial cultivation in Malaysia (Wimalasiri *et al.,* 2021). Agro-ecological requirements for hemp were acquired from international databases and were matched against local climate and soil conditions. The outputs were then used to map the suitability of the crop for all areas within peninsular Malaysia. A seasonal analysis was then used to generate a land suitability map for agricultural areas across five standard land suitability categories (FAO, 1976) (Figure 6).

An economic value and cost-benefit analyses was also carried out using data collected from literature and local sources to simulate the true cost and benefit of growing hemp both for now and future conditions. This analysis provided the first ever evidence base for the economic potential of hemp in Southeast Asia as a prelude to further studies and a more detailed crop modelling effort.

Recommended farming input rates and their costs, crop yield prices and predicted yield data can be used to estimate the likely adoptability of a crop at any location. Statistics on yield and area under cultivation of particular accessions or genotypes of underutilised crops are rarely available either nationally or globally and, therefore, new methods need to be devised to predict the likely performance of any particular ecotype of an underutilised crop at a specific location.

At CFF, efforts have been made to adapt and develop new methods for modelling different genotypes of particular underutilised crops based on scarce or incomplete field data using the concept of a crop `ideotype' first proposed by Donald (1968). For example, Wimalasiri *et al*., (2021) developed an ideotyping method for modelling hemp varieties for new locations. The model has been successfully used to estimate the yield of selected hemp varieties across Malaysia (Wimalasiri, *et al*., 2021; Wimalasiri, *et al*., 2022).

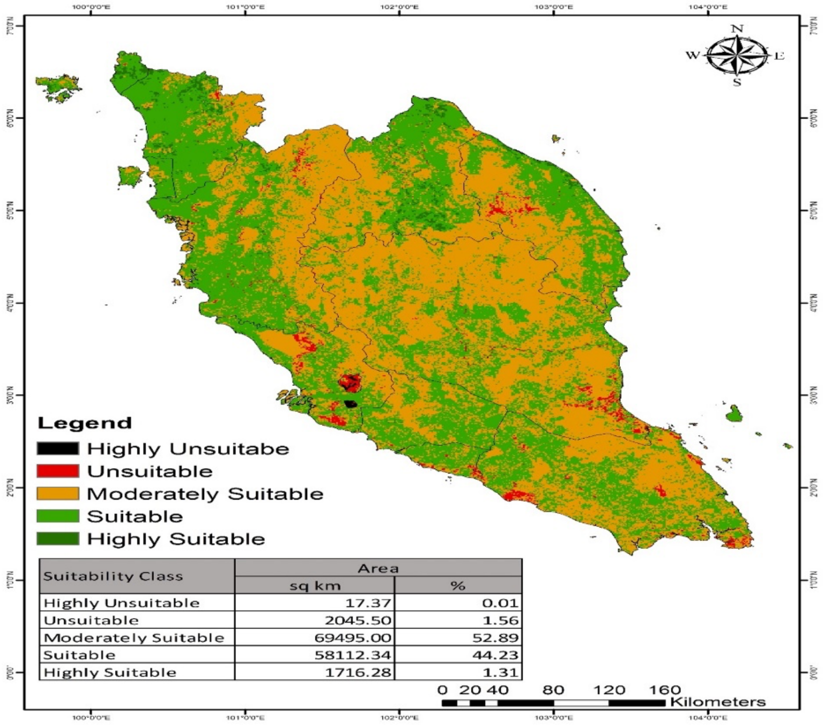


Figure 6: Overall suitability of selected variety of hemp based on FAO land suitability classes. Adapted from (Wimalasiri *et al*., 2021)

**Bambara groundnut in China**

China is by far the world's biggest importer of soybeans with an import bill in 2021 of over $50 bn. These costs have increased further with the inflation in global commodity prices because of the war in Ukraine. The wholesale price of pork, China's staple meat, has risen by about two-thirds in the last year, in part due to higher feed prices (Bloomberg News, 2022). Faced with these challenges, China has the option to further increase its own production of soybean or to identify production areas within China that can be used to grow other crops that can provide equivalent protein and help replace its current requirements from soybean for animal feed and human consumption on land that is not suitable for soybean cultivation.

Using SelectCrop, estimations of net income from the production of a crop can be developed based on estimated crop yield and price per unit of harvested area. Recommended farming inputs, e.g. fertiliser use, have a significant effect on crop yield (Stewart *et al.*, 2005) and also contribute to the crop production cost so must be factored into the cost-benefit analysis. Crop harvested yield prices and the estimated market value are used to obtain estimated gross income from crop production. Predicted net income is obtained by using data of recommended farming inputs costs and estimated gross income. This can be achieved either through crop modelling (Wimalasiri, *et al.,* 2021) or scenario development. In the latter case, SelectCrop can be used to evaluate the agroecological potential for diversification with bambara groundnut in areas of China not currently being used for soybean production (Figure 7). Jahanshiri *et al.*, (2022) also combined openly accessible data with the results of crop shortlisting and suitability assessment to estimate the likely contribution of bambara groundnut to the economy of China. As well as evaluating their potential as alternatives to mainstream crops under current conditions, such an approach can be used to identify climate-resilient alternative crops in response to the likely decline in yields of more favoured mainstream crops as a result of changing climates.

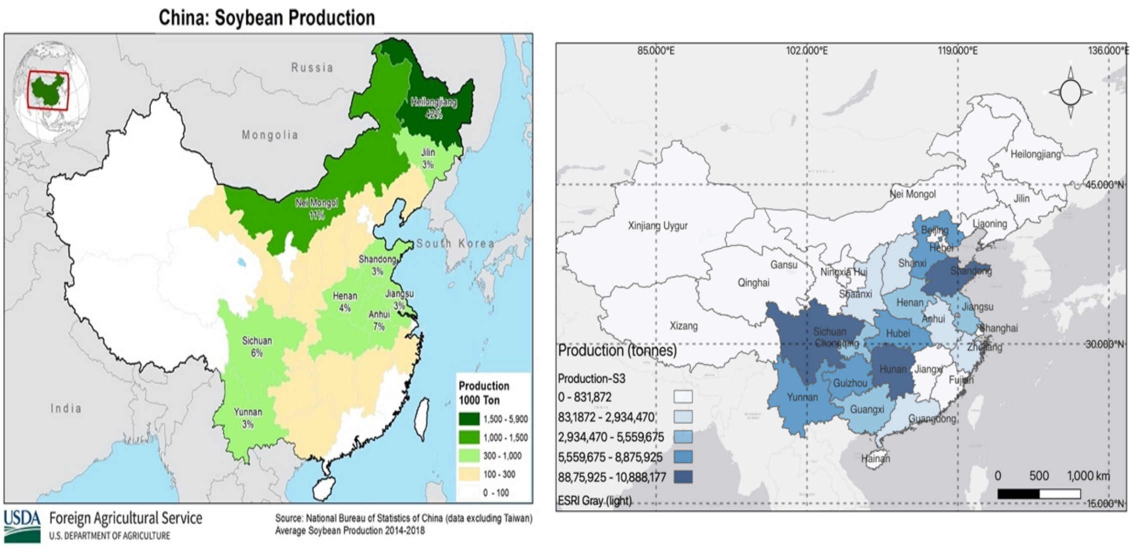


Figure 7: Average soybean production in China (left) and estimated total yearly production of bambara groundnut in China (right). Adapted from (*China - Crop Production Maps*, 2018; Jahanshiri *et al.*, 2022).

## Evaluating the potential distribution of underutilised crops for Italy

As well as evaluating the potential of any single crop species, SelectCrop can be used to identify a range of suitable species at any location or across a whole territory based on the agroecological requirements for different crops. A systematic approach can further be developed to shortlist crops for any locality based on specific criteria identified by the end-user, such as yield, return on investment, nutritional content or quality or climate resilience. Such a preliminary analysis provides a scientific evidence-base to inform policy makers before making widespread changes to existing cropping systems and farming practices. Whilst current policies recognize the impacts that changes in climates and markets are imposing on the Italian food system, the lack of a credible evidence base means that less attention has been given to the development of systematic approaches to identify alternative cropping systems across Italy and the European continent. Wimalasiri *et.al.*, (2022) developed a novel crop suitability shortlisting framework based on (1) agro-ecological shortlisting and (2) rank summation index across Italy to develop a priority list of crops that can help the country achieve food and nutritional security sustainably. To provide an initial shortlist, crops with more than 70% suitability were chosen for further analysis. In the second phase, a multi-criteria ranking index was employed to assign ranks to chosen crops of four main types: (i) cereals and pseudocereals, (ii) legumes, (iii) starchy roots/tubers, and (iv) vegetables. To provide a comprehensive analysis, all the above-mentioned criteria were compared both for major crops that are grown in the region and potential novel underutilised crops that could fit into the agroecological environments of Italy (Figure 8). Out of all crops stored in CropBASE, seven high-ranking crops from the four categories were selected: teff (*Eragrostis tef*) from cereals and pseudocereals, faba bean (*Vicia faba*) and cowpea (*Vigna unguiculata*) from legumes, green arrow arum (*Peltandra virginica*) and Jerusalem artichoke (*Helianthus tuberosus*) from starchy roots/tubers, and fig-leaved gourd (*Cucurbita ficifolia*) and watercress (*Nasturtium officinale*) from vegetables. The crop selection approach used in this study can be employed as part of a more comprehensive national strategy to diversify the existing food systems in Italy or elsewhere for both current environmental and economic conditions and those of the future.

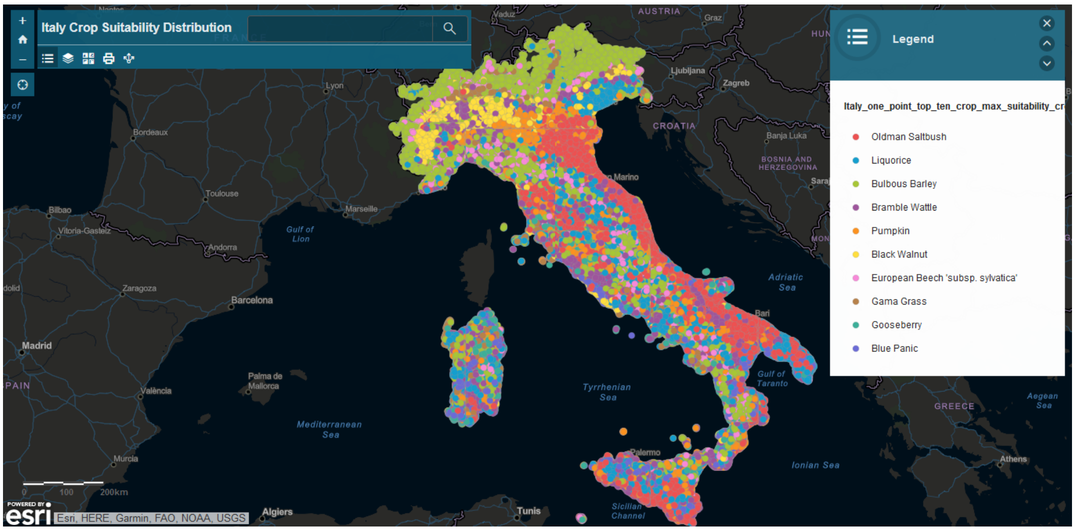


Figure 8: The distribution of the most suitable potential crops for Italy (from crop–climate matching algorithm). Adapted from (Wimalasiri, *et al.*, 2022).

## CONCLUSION

Article 11.1 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA, 2009) refers to the multilateral system of access and benefit-sharing. The multilateral system includes all the plant genetic resources for food and agriculture listed in Annex 1 of the Treaty. Whilst there are at least 30,000 edible plant species of which around 7000 have been cultivated as crops, Annex 1 of the treaty lists only 64 crop and crop complexes (e.g., brassica, that exhibit different forms) that are `under the management and control of the Contracting Parties and in the public domain', - in other words of global significance. Indeed, only a handful of these global crops listed in Annex 1 now provide most of the food consumed by over 7.8 billion people on the planet. The others, and those not listed in Annex 1, enjoy limited, variable and, in some cases, negligible support from international and national research agencies, investors and the private sector. As a result, underutilised crops are *under researched* crops – they and the generations of knowledge associated with them are forgotten. Yet many may contain properties, such as nutritional value, and characteristics, such as climate resilience, that humankind will need if we are to survive and thrive on a hotter and more populated planet. The insouciance of much of the international research community to the fate of forgotten crops may have been understandable when a handful of mainly staple commodity crops were considered sufficient to feed humanity. It is not a wise strategy in an era of changing and unpredictable climates and population growth and environmental degradation.

In 2021, the Global Manifesto on Forgotten Foods was launched in Rome, Italy (https://www.gfar.net/documents/global-manifesto-forgotten-foods). The Manifesto is the result of a broad and intensive consultation process carried out in Africa, Asia-Pacific, Europe and the Middle East and was facilitated by the Global Forum for Agricultural Research and Innovation (GFAR) as part of its Collective Actions to Empower Farmers at the Centre of Innovation. The Manifesto calls for a Global Plan of Action through which the wider use of hitherto forgotten foods can help achieve several of the Sustainable Development Goals of the United Nations, and to the 'Right to Food' and the 'Right to Health' embedded in the Universal Declaration of Human Rights. As far as we are aware, CropBASE is the first global knowledge system dedicated to underutilised and forgotten crops. It already contains information on 2700 crops and tools such as SelectCrop that can provide preliminary evidence on the suitability (or otherwise) of currently underutilised and forgotten crops as potential crops for the future. Linked with other digital systems, the knowledge of farming communities themselves and novel research and modelling, CropBASE has the potential to become an important evidence base to underpin the Global Manifesto on Forgotten Foods that will help conserve and protect indigenous and traditional knowledge and, through equitable partnerships, link this with new knowledge on forgotten crops under current and future climates.

## REFERENCES

Azam-Ali, S. N. (2021). *The Ninth Revolution: Transforming Food Systems for Good*. World Scientific Publishing Company.

Azam-Ali, S., Ahmadzai, H., Choudhury, D., Goh, E. V., Jahanshiri, E., Mabhaudhi, T., Meschinelli, A., Modi, A. T., Nhamo, N., & Olutayo, A. (2023). Marginal Areas and Indigenous People Priorities for Research and Action. In J. von Braun, K. Afsana, L. O. Fresco, & M. H. A. Hassan (Eds.), *Science and Innovations for Food Systems*

*Transformation* (pp. 261–279). Springer International Publishing. https://doi.org/10.1007/978-3-031-15703-5_14

Bloomberg News. (2022, September 22). China Wants to Ensure Food Security by Cutting Amount of Soybeans in Animal Feed. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2022-09-22/china-says-food-security-hinges-on-cutting-overseas-soy-demand

*China—Crop Production Maps*. (2018). https://ipad.fas.usda.gov/rssiws/al/che_cropprod.aspx

Donald, C. M. (1968). The breeding of crop ideotypes. *Euphytica*, *17*(3), 385–403. https://doi.org/10.1007/BF00056241

FAO., S. resources development and conservation service, land and water development division,. (1976). A framework for land evaluation. In *Soils bulletin* (Vol. 32). Food and Agriculture Organisation of the United Nations.

Gregory, P. J., Mayes, S., Hui, C. H., Jahanshiri, E., Julkifle, A., Kuppusamy, G., Kuan, H. W., Lin, T. X., Massawe, F., Suhairi, T. A. S. T. M., & Azam-Ali, S. N. (2019). Crops For the Future (CFF): An overview of research efforts in the adoption of underutilised species. *Planta*, *250*(3), 979–988. https://doi.org/10.1007/s00425-019-03179-2

ITPGRFA. (2009). *International Treaty on Plant Genetic Resources for Food and Agriculture*. FAO Rome, Italy. https://www.fao.org/3/i0510e/i0510e.pdf

Jahanshiri, E., Goh, E. V., Wimalasiri, E. M., Azam-Ali, S., Mayes, S., Tengku Mohd Suhairi, T. A. S., Mohd Nizar, N. M., & Mohd Sinin, S. S. (2022). The potential of Bambara groundnut: An analysis for the People's Republic of China. *Food and Energy Security*, *11*(2), e358. https://doi.org/10.1002/fes3.358

Jahanshiri, E., Mohd Nizar, N. M., Tengku Mohd Suhairi, T. A. S., Gregory, P. J., Mohamed, A. S., Wimalasiri, E. M., & Azam-Ali, S. N. (2020). A Land Evaluation Framework for Agricultural Diversification. *Sustainability*, *12*(8), 3110. https://doi.org/10.3390/su12083110

Jahanshiri, E., & Walker, S. (2015). Agricultural Knowledge-Based Systems at the Age of Semantic Technologies. *International Journal of Knowledge Engineering-IACSIT*, *1*(1), 64–67. https://doi.org/10.7763/IJKE.2015.V1.11

Marahaini, M. N., Jahanshiri, E., Salama, A., & Tengku Adhwa Syaherah, T. M. S. (2018). Linking data across the value chain of underutilised crops—A multidisciplinary approach. *Food Res*, *3*, 108–116.

Mohd Nizar, N. M., Jahanshiri, E., Tharmandram, A. S., Salama, A., Mohd Sinin, S. S., Abdullah, N. J., Zolkepli, H., Wimalasiri, E. M., Mohd Suhairi, T. A. S. T., Hussin, H., Gregory, P. J., & Azam-Ali, S. N. (2021). Underutilised crops database for supporting agricultural diversification. *Computers and Electronics in Agriculture*, *180*, 105920. https://doi.org/10.1016/j.compag.2020.105920

Nizar, N. M. M., Jahanshiri, E., Sinin, S. S. M., Wimalasiri, E. M., Suhairi, T. A. S. T. M., Gregory, P. J., & Azam-Ali, S. N. (2021). Open Data to Support Agricultural Diversification (version October 2020). *Data in Brief*, *35*, 106781. https://doi.org/10.1016/j.dib.2021.106781

Stewart, W. M., Dibb, D. W., Johnston, A. E., & Smyth, T. J. (2005). The Contribution of Commercial Fertilizer Nutrients to Food Production. *Agronomy Journal*, *97*(1), 1–6. https://doi.org/10.2134/agronj2005.0001

Suhairi, T. A. S. T. M., Jahanshiri, E., & Nizar, N. M. M. (2018). Multicriteria land suitability assessment for growing underutilised crop, bambara groundnut in Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science*, *169*(1), 012044. https://doi.org/10.1088/1755-1315/169/1/012044

Suhairi, T. A. S. T., Wimalasiri, E. M., & Jahanshiri, E. (2022). Paving the way for more accurate earth system modelling in Malaysia. *IOP Conference Series: Earth and Environmental Science*, *1016*(1), 012031. https://doi.org/10.1088/1755-1315/1016/1/012031

Wimalasiri, E. M., Jahanshiri, E., Chimonyo, V., Azam-Ali, S. N., & Gregory, P. J. (2021). Crop model ideotyping for agricultural diversification. *MethodsX*, *8*, 101420. https://doi.org/10.1016/j.mex.2021.101420

Wimalasiri, E. M., Jahanshiri, E., Chimonyo, V. G. P., Kuruppuarachchi, N., Suhairi, T. A. S. T. M., Azam-Ali, S. N., & Gregory, P. J. (2021). A framework for the development of hemp (Cannabis sativa L.) as a crop for the future in tropical environments. *Industrial Crops and Products*, *172*, 113999. https://doi.org/10.1016/j.indcrop.2021.113999

Wimalasiri, E. M., Jahanshiri, E., Perego, A., & Azam-Ali, S. N. (2022). A Novel Crop Shortlisting Method for Sustainable Agricultural Diversification across Italy. *Agronomy*, *12*(7), 1636. https://doi.org/10.3390/agronomy12071636

Wimalasiri, E. M., Jahanshiri, E., Suhairi, T. A. S. T. M., Udayangani, H., Mapa, R. B., Karunaratne, A. S., Vidhanarachchi, L. P., & Azam-Ali, S. N. (2020). Basic Soil Data Requirements for Process-Based Crop Models as a Basis for Crop Diversification. *Sustainability*, *12*(18), 7781. https://doi.org/10.3390/su12187781

Wimalasiri, E. M., Jahanshiri, E., Syaherah, T. A., Kuruppuarachchi, N., Chimonyo, V. G. P., Azam-Ali, S. N., & Gregory, P. J. (2022). Datasets for the development of hemp (Cannabis sativa L.) as a crop for the future

in tropical environments (Malaysia). *Data in Brief*, *40*, 107807.
https://doi.org/10.1016/j.dib.2022.107807