Received: 6 October 2021 | Revised: 16 December 2021 | Accepted: 17 December 2021

DOI: 10.1002/fes3.358

ORIGINAL ARTICLE

Food and Energy Security Open Access WILEY

The potential of Bambara groundnut: An analysis for the People's Republic of China

Ebrahim Jahanshiri[1] | **Ee Von Goh**[1] | **Eranga M. Wimalasiri**[1] | **Sayed Azam-Ali**[1] | **Sean Mayes**[1,2] | **Tengku Adhwa Syaherah Tengku Mohd Suhairi**[1] | **Nur Marahaini Mohd Nizar**[1] | **Siti Sarah Mohd Sinin**[1]

[1]Crops For the Future UK, NIAB, Cambridge, UK

[2]School of Biosciences, Nottingham University, Leicestershire, UK

Correspondence
Sean Mayes, Crops For the Future UK, NIAB, 93 Lawrence Weaver Road, Cambridge CB3 0LE, UK.
Email: sean.mayes@nottingham.ac.uk

Funding information
The authors did not receive support from any organization for the submitted work.

Abstract

While China has transformed its economy over recent decades, challenges such as climate change and land degradation have continued to impact its agriculture. These effects along with changes in diets and growing food imports will force China to look for alternative cropping options. Despite the broad potential of Bambara groundnut (*Vigna subterranea* L. Verdc) as a resilient and nutritious underutilized crop, less is known about its potential in Asia. Here, we explore the potential of Bambara groundnut to become a mainstream crop in mainland China. A suitability analysis is presented for Bambara groundnut to examine the degree of seasonal adaptability of this crop against its climate and soil requirements across China. Results showed that the crop has yield potential in areas that can be too marginal for production of other mainstream crops such as soybean (*Glycine max*). If realized, the potential of Bambara groundnut could contribute to China's agriculture and reduce its reliance on vegetable protein imports. Using an average seasonal potential yield of 0.85 *t*/ha over a potential available area of between 55 and 112 million ha (based on 4 land availability scenarios) and modest price of 143 USD/*t*, yearly income between USD 6 and 13 billion can potentially be contributed by widespread cultivation of this crop. As well as food security, this drought-resistant nitrogen-fixing legume could also contribute to land rehabilitation, particularly in the areas where shift in planting dates and land degradation is noticeable. This study demonstrates the need for more investment and research into adoption of Bambara groundnut and other underutilized crops that have the potential to transform agriculture in populous Asian countries.

KEYWORDS

Bambara groundnut, crop potential, food security, People's Republic of China, underutilized crops

1 | INTRODUCTION

1.1 | Climate change impact

During the 20th century, the mean air temperature across China increased by between 0.5 and 0.8°C. This upward trend will continue due to anthropogenic and policy factors such as urbanization, industrialization, and the resultant air pollution (Intergovernmental Panel on Climate Change, 2013; Tian et al., 2016). It is estimated that half of the agricultural land in China is currently used to grow major crops such as rice, wheat, maize, soybean, and tuber crops (Anon, 2014; Tong, Berry, et al., 2016). Soybean is grown on the China's Northeast plain and the plains along the Yellow and Huai rivers which are characterized by clay soils with poor permeability and semi-humid monsoon climates (Dai et al., 2020; Yang et al., 2016). Grain production in China is expected to decline due to several climate impacts (Li, 2018). By 2030, it is projected that under seasonal-drought and climate warming scenarios, maize production is likely to drop by almost 20%, and wheat and rice by 4% and 1.5%, respectively (Li, 2018; Zhou et al., 2017). High temperatures reduce growth duration and phenology and, as a consequence, dry matter accumulation and final crop yield in much of China (Li, 2018). Chen et al. (2013) found that the reduction in soybean yield due to slow and moderate warming scenarios will be 5–10% and 8–22%, respectively.

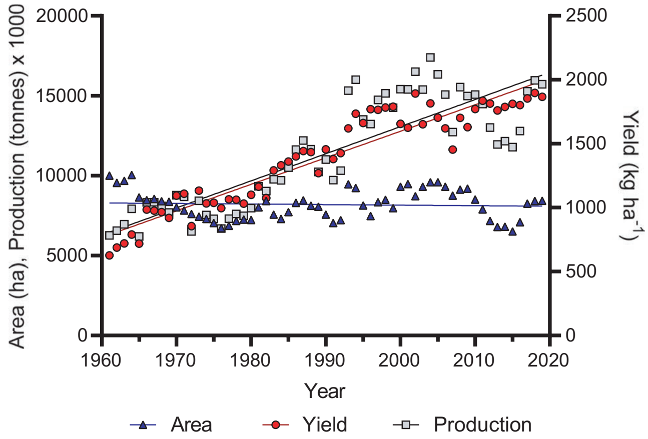


FIGURE 1 Variation of area under cultivation, production, and yield of Soybean in China. Both production and yield showed a significantly ($p < 0.05$) increasing trend while area under cultivation did not show a significant ($p > 0.05$) trend

To improve sustainability in land management, China needs to develop adaptation and mitigation measures to utilize degraded soils for agricultural production and thereby improve land quality and reduce dependency on imports. Along with socioeconomic development and technological advancements, investment in evidence-based diversification with the support of appropriate policy could reduce the pressure on land for agricultural production (Azam-Ali, 2021).

1.2 | Land degradation

Climate variation and socioeconomic factors such as population density and industrial development are associated with income disparity. This, in turn, leads to different models of land use across the country. However, the general pattern of departure from diverse and sustainable approach to highly specialized resource hungry system that is seen elsewhere holds as well for China (Azam-Ali, 2021; Han & Lin, 2021). With a growing population and the rise of the middle class, pressure on land to produce higher yields of commodity crops is mounting (Deng et al., 2008). As the area under cultivation for many crops (including soybean) is either declining or remain constant (Figure 1), a greater dependence on imports of key commodities is anticipated.

In China, the long-term cost of land rehabilitation using cover crops could be much less than cost of inaction. Deng and Li (2016) anticipate that a total of USD 255.45 billion will be required over a 30-year period for land rehabilitation in China. Without rehabilitation of these degraded lands, China will incur a loss of USD 1208.08 billion over the same period.

1.3 | Changes in diets

Like other fast-emerging economies, rapid urbanization and modernization in China has had profound effects on the diets of its citizens. Between 1961 and 2013, there were marked increases in the *per capita* supply of energy-dense and animal-sourced foods, particularly for pork, fish, and seafood (Figure 2.)

The homogenization of local grain production has shifted staple food consumption toward refined cereals (e.g., polished rice, white wheat) and away from more traditional coarse staples (e.g., millet, sorghum), with some of the most substantial changes occurring within groups that most rely on staple foods for nutritional security. Rural areas in the provinces with the tradition of cultivating and consuming multiple coarse staples (Liaoning, Heilongjiang, Shandong, Henan, and Guizhou) showed a decline that corresponds with the substantial decreases in production of such crops in these provinces (Chang et al., 2018). As these coarse staples contain relatively higher nutrient content than refined cereals, the ongoing decline in their consumption decreases the nutritional quality of staple food composition.

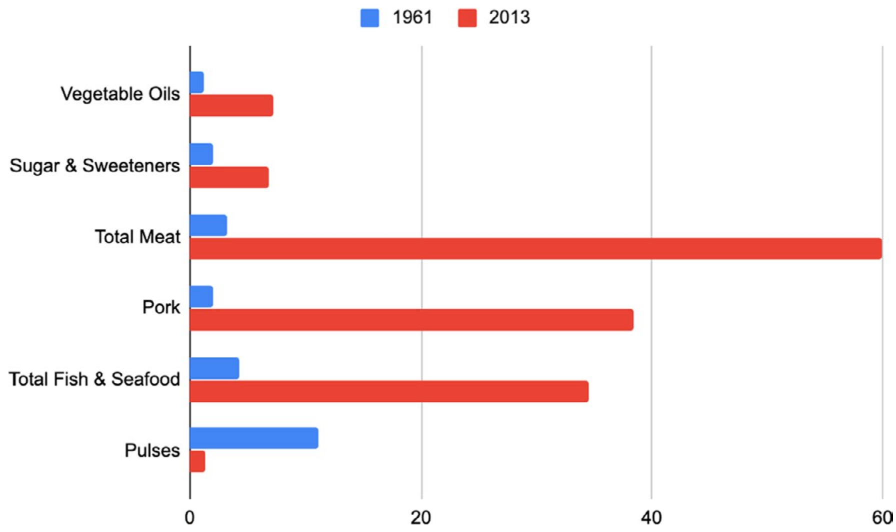


FIGURE 2 Differences in the food supply of different commodities (kg/capita/year) between 1961 and 2013 in China (Adapted from FAO Food Balance Sheets (FAO, 2019; FAOSTAT, 2017))

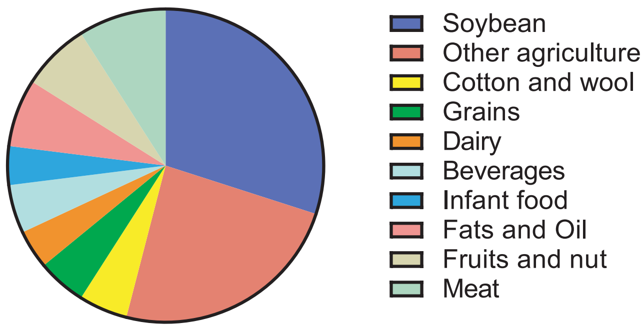


FIGURE 3 China's agricultural imports, by category, 2018. Source: ERS analysis of China customs data from Global Trade Atlas, 2019 (https://www.ers.usda.gov/webdocs/publications/43939/eib-136.pdf?v=0)

As a result of the multiple concurrent transitions in China, the public health effort must now also address the increasing health burden of obesity and other diet-related non-communicable diseases (NCDs), coexisting with the persistent micronutrient deficiencies, mainly among vulnerable groups (Du et al., 2004; Popkin, 2014; Popkin & Du, 2003; Popkin et al., 1993).

To better meet the needs of consumers for safe, nutritious and healthy foods, nutrition-sensitive sustainable agricultural practices and organic food production are increasingly emphasized in China, as is evident by the recent development of the national Food and Nutrition Development Strategy (2021–2035) by the Chinese government.

1.4 | China's import bill

In 2017, China's imports of soybean, rice, wheat, and maize were 95.53 million tons, 4.03 million tons, 4.42 million tons, and 2.83 million tons, respectively (Anon, 2018b). For the same year, the Economic Research Services stated that China's imports of soybeans were valued at USD 12.3 billion from U.S, and USD 20.3 billion from Brazil (Gale et al., 2019). China's demand for soybean accounts for more than 60% of global soybean imports (People's Daily, 2018). In 2018, soybean import accounted for 30% of the value of China's agricultural imports—the largest category in their agricultural import sector (Figure 3). By comparison, the imports of cereal grains were 5%, while fats and oils (including palm, rapeseed, soybean oil, and various other oils) accounted for 7% of agricultural imports.

1.5 | Soybean as an example

Figure 4 shows average production of soybean in China from 2010 to 2014. Decreasing soybean production is a major concern for the Chinese food industry. Chinese farmers are ever more pressurized to produce more on diminishing land resources that are suitable for high input, high maintenance crops, and varieties (Zhang & Changhe, 2020). Most soybean production occurs in the northeastern provinces with low productivity in the southern provinces. As the quality of agricultural land diminishes, such valuable resources are left underutilized. It is therefore evident that for China to be self-sufficient, both now and in the future, complementary options beyond mainstream crops for production can play a role.

China has made massive investments in developing high-yielding varieties of major crops to meet its food and animal feed needs. However, such crops are now increasingly vulnerable to changing climate and land degradation (Sections 1.1–2). Many areas of the country are increasingly marginal for high-yielding cultivars of major crops making them unsustainable for agricultural production.

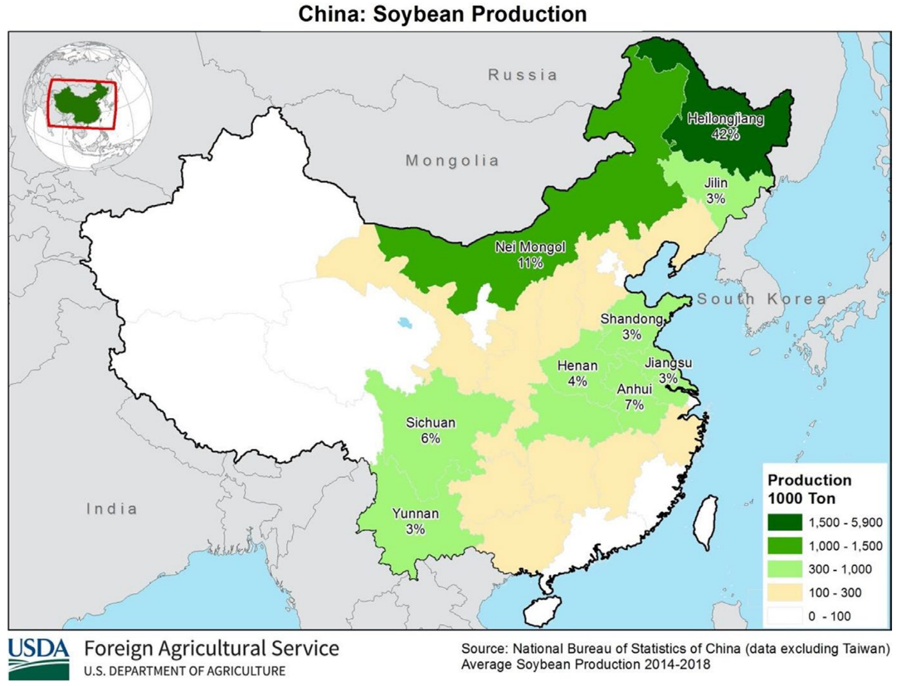


FIGURE 4 Average soybean production in China 2010–2018. Adapted from USDA (Anon, 2018a)

TABLE 1 Nutritional value of Bambara groundnut as compared with soybean (Nizar et al., 2021)

Element	Bambara groundnut	Soybean
Moisture g (or %)/100 g	9.7	8.5
Ash g (or %)/100 g	2.5	4.9
Total dietary fiber g (or %)/100 g	6.5	9.3
Protein g (or %)/100 g	21.0	36.5
Fat g (or %)/100 g	6.0	19.9
Carbohydrates g (or %)/100 g	63.0	30.2

Reliance on only major crops is likely to make economic growth more uncertain.

The balance between climate challenges for major crops and land degradation requires disruptive innovations that include introduction of new crops that are resilient to climate change, can be the source of nutritious and marketable products, and can utilize existing capacities within China. Evaluating the possibilities that underutilized crops provide to diversify China's agri-food system and reduce the need for costly imports should become a priority for national development.

Many underutilized crops can be developed to complement the cropping systems in China (Mengxiao, 2001). However, attention needs to also be given to developing resilient crops that require fewer inputs and can be grown in low fertility soils, improving ecological properties of farming systems such as interaction between species, improving sustainability, and enhancing ecosystem services (Cong et al., 2021). Utilizing crops that can directly contribute to food and nutrition security while providing new opportunities for local farming communities to develop food products and processing businesses will contribute to filling the income gap in China.

Bambara groundnut (*Vigna subterranea* (*L.*) *Verdc.*) is an African legume that is grown extensively in sub-Saharan regions. The crop is also shown be able to grow in tropical South-East Asia with comparatively lower economic importance. This has given the crop its reputation in terms of its resiliency; producing yields on lands that are marginal for mainstream crops such as soybean (Hussin et al., 2020; Mayes et al., 2019; Tan et al., 2020). In addition to its climate resilience and nutritional content (Table 1), Bambara groundnut has several traits such as nitrogen fixation, stress tolerance, and an ability to grow in low-input systems that make it an ideal candidate crop for land rehabilitation. High concentration of carbohydrates together with the moderately high concentration of protein in Bambara groundnut has also made it a potential candidate for mixed-cropping and rotational systems in dry areas, as a complement to cereals (Section 3.3).

Unlike mainstream crops, Bambara groundnut has received less support from international and governmental agencies for its research and development. An important aspect of the introduction of a particular crop is the simultaneous adoption by all stakeholders and initial support from both public and private sectors. This process can be particularly streamlined in countries with enough income per capita such as China. Therefore, in this paper, we hypothesize the suitability of Bambara groundnut as a globally neglected crop with no history of cultivation in China. We then relate the findings against current issues and future trends and provide motivation for the adoption of this crop in China using a multidisciplinary approach.

2 | MATERIALS AND METHODS

2.1 | General land suitability

Current and future agro-ecological suitability of a crop at a location can estimated by contrasting its environmental requirements against local conditions (Peter et al., 2020). A suitability analysis of Bambara groundnut was produced by estimating the suitability for 12 possible calendar-year seasons against climate (temperature) and soil (pH, depth, and texture) using spatially explicit data of 1 km resolution (Jahanshiri et al., 2020; Suhairi et al., 2018). This analysis can provide a useful outlook for adaptability at global and national levels. The suitability map that is derived using the abovementioned methodology needs to be contrasted against local land use before it can be useful for any regional and local decision making. To estimate the potential of land for growing Bambara groundnut, current cropped areas were subtracted from the total agriculture land areas to include only those areas that are currently uncultivated (built environment and water bodies, etc.).

To reach at possible available areas for farming Bambara groundnut, available cropland data from two sources were acquired to develop 4 production scenarios. We first used GlobCover data (Bontemps et al., 2013) that distinguishes rainfed areas from irrigated croplands to develop 3 production scenarios based on the result of agro-ecological suitability for all rainfed lands in China. The data were then aggregated per province to make it consistent with the national land-use data published by Bureau of Statistics China (2020) that provides total and irrigated area of cultivated land per province across China. Therefore, Scenario 4 was developed by subtracting irrigated area from the total cultivated area (Appendix 2). Figure 5 shows estimated total potential production of Bambara groundnut in China based on Scenario 1.

3 | RESULTS AND DISCUSSION

3.1 | Production scenarios for Bambara groundnut

The agro-ecological requirements of Bambara groundnut are generally met across much of China where there is no previous history of its cultivation (Appendix 1). For potential production, currently irrigated areas were subtracted from the total suitable areas for Bambara groundnut. The remaining areas, depending on the chosen scenario, represent potential agricultural land for Bambara groundnut.

Using the average potential areas with a modestly reported yield of 0.85 *t*/ha (Hussin et al., 2020; Mayes et al., 2019) for one optimal season (June–September) and modest price of 143 USD/T, a total of USD 6 to 13 billions of yearly income can potentially be contributed to the economy (Table 2 and Appendix 2). The price that is used for calculation of income is the minimum figure obtained from the price of Bambara groundnut in a country that still is considered underutilized (Malaysia) based on the authors' observations. The prices are however reported to

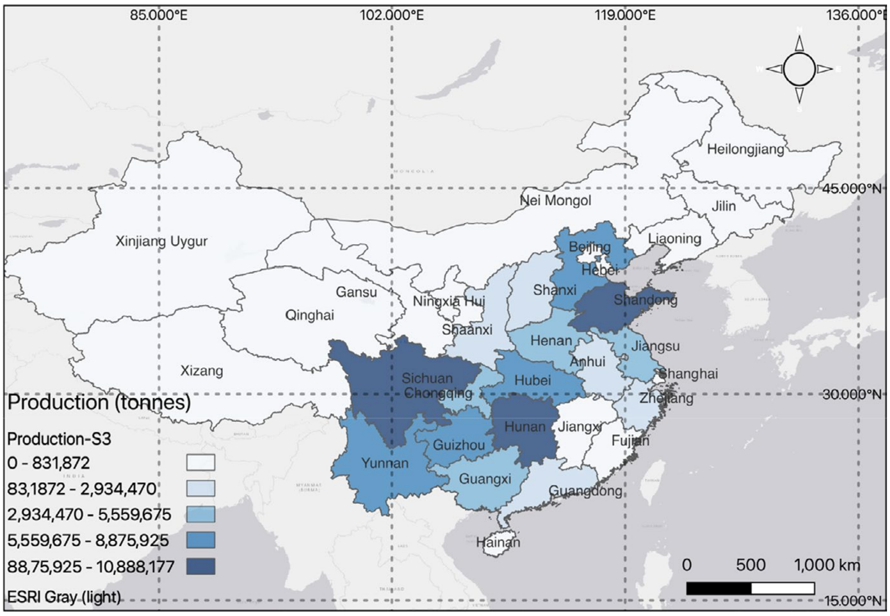


FIGURE 5 Estimated total yearly production of Bambara groundnut in China (Scenario 1, Section 3.1)

TABLE 2 Land statistics and potential production and income scenarios for Bambara groundnut

Province	Potential available land (ha)	Estimated total production (t)[a]	Potential protein supply (t)	Potential carbohydrate supply (t)	Potential income (USD)[b]
Scenario 1	55,508,199	47,181,969	9,908,213	29,724,640	6,747,021,531
Scenario 2	70,034,310	59,529,164	12,501,124	37,503,373	8,512,670,389
Scenario 3	112,614,967	95,722,722	20,101,772	60,305,315	13,688,349,185
Scenario 4	66,202,200	56,271,870	11,817,093	35,451,278	8,046,877,410

[a]Average potential yield 0.85 t/ha (Mayes et al., 2019).

[b]Potential price 143 USD/t (based on local price in Malaysia, obtained from CFFRC's CONNECT project).

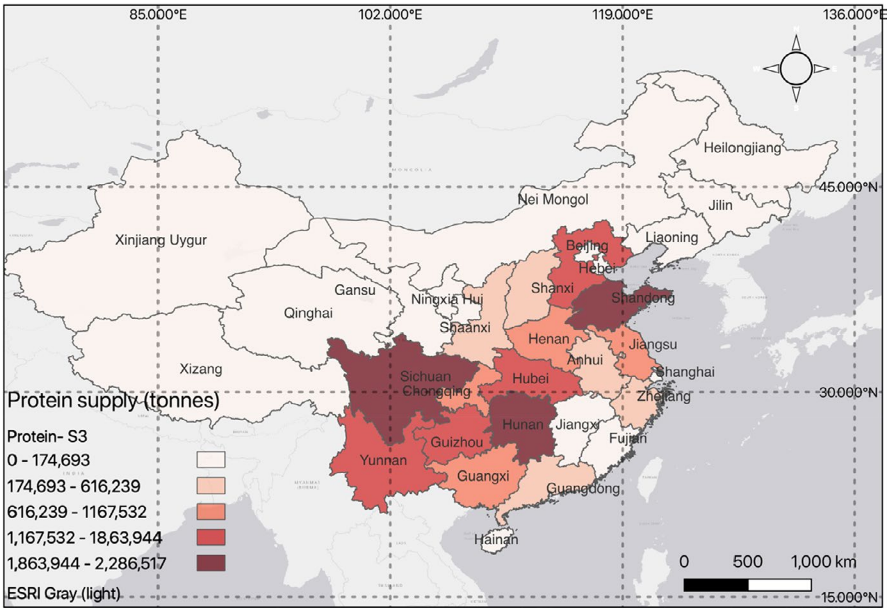


FIGURE 6 Potential contribution of Bambara groundnut to reducing protein imports of China under Scenario 3

be much higher in the continent of Africa where this crop is considered a commodity (look at the report by Cook (2017)).

Figure 5 shows the production based on Scenario 3 that estimates a maximum total production 10 million tonnes of Bambara groundnut as an established crop in China.

The present agro-ecological suitability analysis permits adaptability estimation for a crop across a vast territory since it does not require any knowledge from local field trials. However, it also fails to recommend specific cropping system (irrigated/rainfed) and management requirements (fertilizer, chemicals, etc.). It is shown that Bambara groundnut can be a suitable crop in areas with >800 mm of annual rain (Mayes et al., 2019) and areas with erratic rainfall patterns. Therefore, provided other conditions are properly met, and both rainfed and irrigated systems can be considered for production. Nevertheless, to provide a more realistic estimate of regional crop performance, currently irrigated lands were not considered in all 4 scenarios above, and this is because those areas are already allocated for production of crops such as maize and rice and therefore should not be used for new crops. Cultivated areas (general agricultural and arable lands) are shown to have reached at a stable level since 1990s in China (The World Bank n.d.), and therefore, the land cover data such as GlobCover can still be used to develop estimates of production.

For economic Scenario 1, only "highly suitable" areas were considered, and therefore, agricultural land for Beijing, Gansu, Hebei, Heilongjiang, Jiangxi, Jilin, Liaoning Nei Mongol, Ningxia Hui, Qinghai, Shanghai, Shanxi, Tianjin, Xinjiang, Uygur, and Xizang (Tibet) provinces was evaluated as unsuitable for growing Bambara groundnut without further breeding work. For Scenario 2, "suitable" areas were added to the "highly suitable" areas in Scenario 1, and therefore, the total land increased; however, Heilongjiang, Jiangxi, Liaoning, Ningxia Hui, Qinghai, Shanghai, Shanxi, Tianjin, Xinjiang Uygur, and Xizang (Tibet) provinces were still unsuitable for production. For Scenario 3, "moderately suitable" areas were added to the areas under Scenarios 1 and 2. However, Heilongjiang, Liaoning, Ningxia Hui, and Shanghai provinces remained unsuitable for production (Table 2 and Appendix 1). Based on the estimated total production, potential contribution of Bambara groundnut to reduce the need for protein import is illustrated in Figure 6. The contribution of the crop in China's southern provinces to the national plant-based protein needs is evident.

With the skyrocketing demand for vegetable protein, the production deficit for the grain legumes particularly for animal feed in China is driving concerns. This along with the concerns on food security at the face of global food supply challenges caused by COVID-19 pandemic (Espitia et al., 2020) and lower interest of farmers to grow soybean (Gu & Maguire, 2021) will force China to examine diversification strategies among other solutions.

This preliminary estimate of suitability for a globally neglected crop justifies further investigation into local adoption of the crop, particularly in the provinces where Bambara groundnut is highly suitable and, other legumes such as soybean are not grown. This is evident by contrasting the areas in Figures 4 and 5. The amount of land available to agriculture in each province after reducing the currently utilized land was used to develop three scenarios for potential income generation from cultivation of Bambara groundnut (Table 2 and Appendix 2).

3.2 | Potential uses for Bambara groundnut in China

Notwithstanding the many other and undeniably varied potentials and uses of Bambara groundnut, below is the review of its food and non-food uses that we considered applicable in China's food scene as a replacement or partial substitution of soybean. Table 3 shows potential uses and areas that this crop can complement current needs in the foods and non-food industries. Bambara groundnut shares many processing characteristics with soybean. Both legumes are known to be hard-to-cook (HTC) and hard-to-mill (HTM). They share similarly long cooking time, that is, approximately 3 to 4 h (Mubaiwa et al., 2017), and similar requirements for pre-cooking processes to reduce cooking time (Mubaiwa et al., 2017; Destro et al., 2013). The techniques used to process soybean into various food products are equally applicable to Bambara groundnut (Table 3). Hence, this application can potentially use the current infrastructure for food processing across the country and add to the protein and possibly carbohydrate needs as mentioned in Section 3.1 without much barriers in terms of acceptance by food producers.

TABLE 3 Potential uses of Bambara groundnut in the Chinese context in comparison with soybean

Food use	
Bean flours and products	Soybean flour is widely used in industry as an ingredient to boost the protein contents of many food items such as bakery and pasta. Like soybean flour, Bambara groundnut flours can be made from roasted beans that have been ground into fine flour. Bambara flour has been successfully used to produce staples such as noodles, bread, biscuits, and cakes (Ekthamasut, 2013; Abidin et al., 2014; Alozie et al., 2009; Hussin et al., 2020; Nwadi et al., 2020; Uchenna & Omolayo, 2017). While the protein content is lower for Bambara groundnut than soybean, there is no need to de-fat Bambara groundnut prior to grinding
Non-dairy alternatives	Like much of Asia, lactose intolerance is widely prevalent at about 90% in China (Yang et al., 2013). Soymilk is the aqueous extract of soy protein, and it is free of lactose and cholesterol. Therefore, it is considered a healthy beverage and an important and popular alternative to dairy milk for a population that is lactose-intolerant. Similarly, non-dairy Bambara groundnut milk (Murevanhema & Jideani, 2013, 2015) and baby weaning food (Adebayo-Oyetoro et al., 2011; Aloysius & Ajawubu, 2013) have been successfully produced.
Condiments	Soybean is fermented in many ways to produce various fermented bean pastes and soy sauces that are quintessential ingredients of the Chinese cuisine. These different types of condiments have the same characteristic taste, termed"umami" or savory taste. The presence of protein in the ingredient, coupled with a deep fermentation process, produces an abundance of free amino acids. Of which, the free L-glutamic acid is a key compound responsible for the umami taste (Lioe et al., 2010). Bambara groundnut, with its high glutamic acid content (Adebowale et al., 2011), can be a good candidate to replace soybean in the production of those savory condiments.
Non-food use	
Animal feeds	As China's appetite for animal-sourced foods increases, so too has its use of soybean meal. Several studies have demonstrated the promising use of Bambara groundnut meal in animal feeds (Enyidi & Mgbenka, 2015; Mahala & Mohammed, 2010; Oso et al., 2013).
Biomass/Energy	Shell and biomass are shown to have potential for bio-char and bio-ethanol production (Mohammed et al., 2017; Okuofu et al., 2020; Okwu et al., 2018)

3.3 | Cropping systems

China has contributed many crops and cropping systems through its 7000 years of history in agricultural development (Mengxiao, 2001); however, agricultural diversification is key to long-term sustainability of its current production systems. Strategies such as intercropping, mixed cropping, and crop rotation are shown to improve resource use efficiency in a cropping system. Cong et al. (2021) devised a strategy for crop diversification across China to elevate sustainability of cropping systems while improving diets and increasing farmers' income. For northwest China, they suggest implementation of intercropping systems due to possibility of growing only one crop per year. In this regard, intercropping of maize and legumes such as Bambara groundnut could improve the water use efficiency and income of the local farmers (Alhassan & Egbe, 2014; Chimonyo et al., 2020). Intercropping is also suggested as a new strategy to cope with the high incidents of pest and diseases in southwest China. Introduction of new crops that are tolerant to dominant pest and diseases could help with yield improvements. It is also shown that this crop can benefit the pollinators and in turn improve the sustainability of ecosystem services that led to increase in food production in Africa (Otieno et al., 2020). In the areas at the northeast China, Bambara groundnut could be also be a viable option as a cover crop (Azam-Ali et al., 2001), intercropped with maize to preserve water with the support from regulatory bodies. Cong et al. (2021) also suggest legume-based cropping systems for the southern China with an abundance of water, but there is a need to improve soil quality in the hilly regions. Bambara groundnut could be a source of green manure for the rice systems in this area and as a crop for rotations systems (Minnaar-Ontong et al., 2021).

3.4 | A framework the development of Bambara groundnut in China

As the global food security projections draw an uncertain future (van Dijk et al., 2021), nations should start devising pathways that ensure maximum production efficiency based on locally and globally neglected crops. The introduction of Bambara groundnut could start by utilizing marginal areas within the Scenario 1 or 4 where no major crop is grown and the land is potentially vacant/idle and where local farmers are willing to utilize such lands for new crops (Tong, Niu, & Fan, 2016) and where the suitability analysis shows, this crop is highly suitable. Upon establishment of the crop, all lands under Scenarios 2 and 3 can also be utilized. Following the preliminary analysis presented earlier, a more detailed plan can be developed for the introduction and adoption of Bambara groundnut in China. Depending on the spatial scale of diversification operations, a systematic approach to estimating the general land suitability, modeling the performance, and documenting food and non-food uses of the crop can be developed through national consultation. In order to determine exact cultivar or landrace that can be suitable at any location, detailed simulation modeling can be performed to estimate the likely performance of the crop at any location using the available genetic resources that are already available for Bambara groundnut (Mayes et al., 2019; Wimalasiri, Jahanshiri, Chimonyo, Azam-Ali, & Gregory, 2021; Wimalasiri, Jahanshiri, Chimonyo, Kuruppuarachchi, et al., 2021). Once a few varieties of the crop are established, the government or private sector will be able to consult with commercial entities to further develop the crop in the country and find commercial use cases for both domestic use and export due to high nutrition value and climate resilience of this crop (Figure 7).

3.5 | Possible Challenges

Agriculture as an industry and as system of interlocked components is always seeking alternatives through novel innovations. Introduction and adoption of new crops in new environments is considered risky (Lockeretz, 1988). In a traditional sense, and without considering recent advancements in breeding, data science, and technology, challenges might seem multidimensional, from variety selection and agronomic issues to transfer of knowledge and adaptation of highly specialized industry and development of products to the new crops.

In traditional view of crop introduction, breeders should select a few varieties that can possibly perform well at a location (Figure 7). This selection process, however, has been accelerated with the introduction of rapid genome alteration methods that are developed specifically for underutilized crops such as Bambara groundnut. Mayes et al. (2012) provide a primer to such methods that are applied to genotypes of Bambara groundnut and (Gregory et al., 2019) provide a practical example that specifically tackle line selection and agronomic issues related to Bambara groundnut in a tropical environment. The article also shows how agronomic trials can be accelerated with a concerted effort of scientists from different disciplines, the food systems approach. All the other scientific efforts such as development of products for food, feed, and energy can be done simultaneously using the material that is developed through agronomic trials. Such

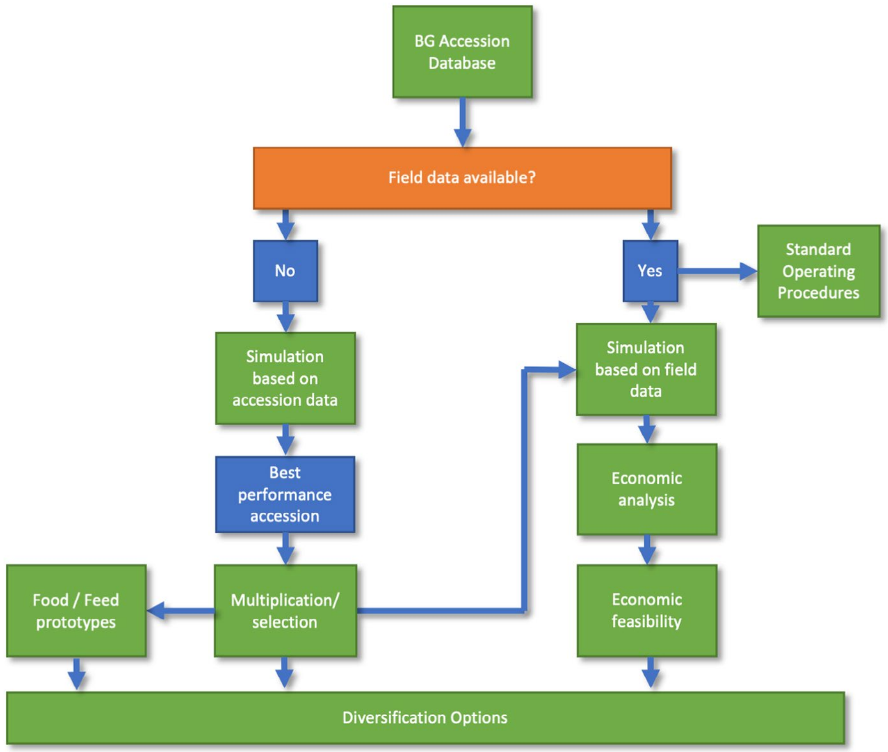


FIGURE 7 Schematics of proposed development framework for Bambara groundnut. Adapted from (Jahanshiri et al., 2020)

consorted efforts will only shorten the amount of time that is required to develop scientific insights surrounding a new crop at a new environment (Hussin et al., 2020; Katya et al., 2017; Tan et al., 2020).

A traditional view to knowledge dissemination would lead to prolonged process of uptake of a new crop given life cycle and attention span of scientific community and the public (Azam-Ali, 2021). However, with the recent advances in databases, modeling and dissemination, modes of knowledge transfer in agriculture are revolutionized. With data that are collected along the research value chain, simulation of crop performance is becoming more and more accessible. For example, Wimalasiri, Jahanshiri, Chimonyo, Azam-Ali, & Gregory (2021) and Wimalasiri, Jahanshiri, Chimonyo, Kuruppuarachchi, et al. (2021) used data from different disciplines to develop a framework for the adoption of hemp in tropical environments. Such simulations about the past and present status of productivity of a crop will simply be impossible without a consorted data effort that is underway in the agricultural community. An important aspect of adoption of crop is uncertainty in investment returns for a particular crop. Wimalasiri, Jahanshiri, Chimonyo, Azam-Ali, & Gregory (2021) and Wimalasiri, Jahanshiri, Chimonyo, Kuruppuarachchi, et al. (2021) show that with enough local information, it is possible to develop an evidence base for the kind of returns that are likely for a particular crop.

3.6 | Final thoughts

Land as a non-renewable resource plays a major role in all developing economies. In this regard, careful planning and execution of diverse land-use options is necessary for countries such as China that are already affected by complex challenges such as climate change and land degradation. Global production is presently confined to a few highly specialized crops that require the best types of land and resources to grow and yield. However, there are many crops that are already domesticated and utilized in different parts but are globally neglected and underutilized (Azam-Ali, 2021). These crops that are often highly adapted to marginal environments will play a bigger role in the future of agriculture. In this regard, tapping into these resources is an investment that any country should make to future proof its food security plans and climate adaptation and mitigation strategies. Both published and unpublished data indicate that this crop is grown in some Asian countries such Indonesia and Thailand and Malaysia (Azam-Ali et al., 2001; Mayes et al., 2019; Redjeki et al., 2011; Tan et al., 2020). However, despite Bambara groundnut's potential to become a staple legume in Asia, uptake remain small for reasons such as prevalence of import of food and food industries that formed around material that is imported rather than produced locally. This obviously could change with increased awareness in policy and business communities.

4 | CONCLUSION

Evaluating the potential of underutilized and neglected crops such as Bambara groundnut can help transform China's agriculture and reduce its dependencies on food imports, while improving land quality and diets. The agrobiodiversity elements are often neglected in traditional land development systems that frequently promote monocropping systems for a narrow cohort of mainstream staples. New methods for crop selection are being developed to help stakeholders diversify their farming systems and adopt more ecologically adaptable crops and cropping systems. Using curated and publicly available data, we provided a first case scenario for a sustainable cropping option in China involving Bambara groundnut as a resilient underutilized crop with many potentials for food and nutrition security and land rehabilitation. The "evidence-based options" that are the result of "digital land evaluation" using state-of-the-art methods can be tailor-made for production scenarios that are aligned with China's Comprehensive Agricultural Plan (CAP) and United Nations Sustainable Development Goals.

ACKNOWLEDGMENTS

Authors would like to colleagues at Crops For the Future for their help and support.

CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

ORCID

Ebrahim Jahanshiri https://orcid.org/0000-0002-9110-1880

Sean Mayes https://orcid.org/0000-0003-4770-3662

REFERENCES

Abidin, N. S. A., Mat, M. H. C., Rukunudin, I. H., & Jaafar, M. N. (2014). Optimization of Improved Instant Noodle from Bambara Groundnut (*Vigna Subterranea*) Flour in Terms of Chemical and Texture Characteristics Using Response Surface Methodology (RSM). *Australian Journal of Basic and Applied Sciences*, *8*(4), 643–648.

Adebayo-Oyetoro, A. O., Olatidoye, O. P., Ogundipe, O. O., Balogun, O. I., & Faboya, A. O. (2011). Quality Evaluation of Weaning Food Produced from Blend of Ofada Rice (*Oryza sativa*) and Bambara Groundnut (*Voandzeia Subterranean* L.). *Electronic Journal of Environmental, Agricultural and Food Chemistry*, *10*(6), 2322–2330.

Adebowale, Y. A., Schwarzenbolz, U., & Henle, T. (2011). Protein isolates from Bambara groundnut (*Voandzeia Subterranean* L.): Chemical characterization and functional properties. *International Journal of Food Properties*, *14*(4), 758–775.

Alhassan, G. A., & Egbe, M. O. (2014). Bambara groundnut/maize intercropping: Effects of planting densities in southern Guinea Savanna of Nigeria. *African Journal of Agricultural Research*, *9*(4), 479–486. https://doi.org/10.5897/AJAR2013.7955

Aloysius, M. T., & Ajawubu, I. O. (2013). Formulation of infant weaning food from Sorghum and Bambara-ground nut. *International Journal of Advancement in Biological Sciences*, *6*, 89–98.

Alozie, Y. E., Iyam, M. A., Lawal, O., Udofia, U., & Ani, I. F. (2009). Utilization of Bambara groundnut flour blends in bread production. *Journal of Food Technology*, *7*(4), 111–114.

Anon (2014). *Ministry of agriculture and rural affairs*. China Agriculture Press.

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

Anon (2018b). General Administration of Customs of the People's Republic of China. (2018). China Customs Statistics. http://english.customs.gov.cn/Statistics/Statistics?ColumnId=3

Azam-Ali, S. N. (2021). *The ninth revolution: Transforming food systems for good*. World Scientific Publishing Company.

Azam-Ali, S. N., Sesay, A., Karikari, S. K., Massawe, F. J., Aguilar-Manjarrez, J., Bannayan, M., & Hampson, K. J. (2001). Assessing the potential of an underutilized crop – a case study using Bambara groundnut. *Experimental Agriculture*, *37*(4), 433–472. https://doi.org/10.1017/S0014479701000412

Bontemps, S., Defourny, P., Radoux, J., Van Bogaert, E., Lamarche, C., Achard, F., Mayaux, P., Boettcher, M., Brockmann, C., Kirches, G., Zülkhe, M., Kalogirou, V., & Arino, O. (2013). *Consistent global land cover maps for climate modeling communities*. Edinburgh.

Bureau of Statistics China. (2020). *China Statistical Yearbook*. China Customs. http://english.customs.gov.cn/Statistics/Statistics?ColumnId=3

Chang, X., DeFries, R. S., Liu, L., & Davis, K. (2018). Understanding dietary and staple food transitions in china from multiple scales. *PLoS One*, *13*(4), 195775. https://doi.org/10.1371/journal.pone.0195775

Chen, S., Chen, X. & Xu, J. (2013). Impacts of climate change on corn and soybean yields in China. Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC.

Chimonyo, V. G. P., Wimalasiri, E. M., Kunz, R., Modi, A. T., & Mabhaudhi, T. (2020). Optimizing traditional cropping systems under climate change: A case of maize landraces and Bambara groundnut. *Frontiers in Sustainable Food Systems*, *4*, 1–19. https://doi.org/10.3389/fsufs.2020.562568

Cong, W.-F., Zhang, C., Li, C., Wang, G., & Zhang, F. (2021). Designing diversified cropping systems in China: Theory, approaches and implementation. *Frontiers of Agricultural Science and Engineering*, *8*(3), 362–372. https://doi.org/10.15302/J-FASE-2021392

Cook, D. (2017). Small scale farmers utilization and perceptions of Bambara groundnut production in South Africa: A case study in a semi-arid region of Limpopo. University of Cape Town.

Dai, C., Qin, X. S., Lu, W. T., & Huang, Y. (2020). Assessing adaptation measures on agricultural water productivity under climate change: A case study of Huai River Basin, China. *Science of the Total Environment*, *721*, 137777. https://doi.org/10.1016/j.scitotenv.2020.137777

Deng, X. Z., Huang, J. K., Rozelle, S., & Uchida, E. (2008). Growth, population and industrialization, and urban land expansion of China. *Journal of Urban Economics*, *63*(1), 96–115. https://doi.org/10.1016/j.jue.2006.12.006

Deng, X., & Li, Z. (2016). Economics of Land Degradation in China. In E. Nkonya, A. Mirzabaev, & J. von Braun (Eds.), *Economics of land degradation and improvement – A global assessment for sustainable development* (pp. 385–399). Springer International Publishing.

Destro D., Faria A. P., Destro T. M., de Faria R. T., Gonçalves L. S. A., & Lima W. F. (2013). Food type soybean cooking time: A review. *Crop Breeding and Applied Biotechnology*, *13*(3), 194–199. http://dx.doi.org/10.1590/s1984-70332013000300007

Du, S., Mroz, T. A., Zhai, F., & Popkin, B. M. (2004). Rapid income growth adversely affects diet quality in China—Particularly for the poor! *Social Science & Medicine*, *59*(7), 1505–1515. https://doi.org/10.1016/j.socscimed.2004.01.021

Ekthamasut, K. (2013). The effect of blending rice flour with Bambara groundnut flour on the quality of flat rice noodles. *University of the Thai Chamber of Commerce Journal*, *33*(2).

Enyidi, U. D., & Mgbenka, B. O. M. (2015). Replacement of fish meal with bambara nut waste meal in the diets of Larval African Catfish Clarias Gariepinus Burchell (1822). *British Journal of Applied Science & Technology*, *5*(6), 526–537. https://doi.org/10.9734/BJAST/2015/12886

Espitia, A., Rocha, N., & Ruta, M. (2020). *Covid-19 and food protectionism: The impact of the pandemic and export restrictions on world food markets*. World Bank.

FAO (2019). *Food balance sheets for year 1961*. FAO.

FAOSTAT (2017). *Production quantities of rice, paddy by country average from 1994*. FAOSTAT.

Gale, F., Valdes, C., & Ash, M. (2019). *A Report from the Economic Research Service: Interdependence of China, United States, and Brazil in Soybean Trade*. United States of Agricultural Department.

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

Gu, H., & Maguire, G. (2021). *Analysis: China's farmers dump other crops for corn on bumper profit pull*. Reuters.

Han, H., & Lin, H. (2021). Patterns of agricultural diversification in China and its policy implications for agricultural modernization. *International Journal of Environmental Research and Public Health*, *18*(9), 4978. https://doi.org/10.3390/ijerph18094978

Hussin, H., Gregory, P. J., Julkifle, A. L., Sethuraman, G., Tan, X. L., Razi, F., & Azam-Ali, S. N. (2020). Enhancing the nutritional profile of noodles with Bambara groundnut (Vigna Subterranea) and Moringa (Moringa Oleifera): A food system approach. *Frontiers in Sustainable Food Systems*, *4*, 1–11. https://doi.org/10.3389/fsufs.2020.00059

Intergovernmental Panel on Climate Change (2013). Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. http://www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf

Jahanshiri, E., Nizar, N. M. M., Suhairi, T. A. S. T. M., 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

Katya, K., Borsra, M. Z. S., Kuppusamy, G., Herriman, M., & Azam-Ali, S. N. (2017). Preliminary study to evaluate the efficacy of Bambara groundnut (*Vigna Subterranea* (L.) Verdc.) meal as the dietary carbohydrate source in Nile Tilapia, *Oreochromis niloticus*. *Madridge Journal of Aquaculture Research & Development*, *1*(1), 13–17. https://doi.org/10.18689/mjard-1000103

Li, M. (2018). IFPRI Blog: Research Post—Climate change to adversely impact grain production in China by [Research Center]. IFPRI Blog : Research Post. http://www.ifpri.org/blog/climate-change-adversely-impact-grain-production-china-2030

Lioe, H. N., Selamat, J., & Yasuda, M. (2010). Soy Sauce and its Umami taste: A link from the past to current situation. *Journal of Food Science*, *75*(3), R71–76. https://doi.org/10.1111/j.1750-3841.2010.01529.x

Lockeretz, W. (1988). Agricultural diversification by crop introduction. *Food Policy*, *13*(2), 154–166. https://doi.org/10.1016/0306-9192(88)90028-0

Mahala, A. G., & Mohammed, A. A. A. (2010). Nutritive evaluation of Bambara groundnut (Vigna Subterranean) pods, seeds and hull as animal feeds. *Journal of Applied Sciences Research*, *6*(5), 383–386.

Mayes, S., Ho, W. K., Chai, H. H., Gao, X., Kundy, A. C., Mateva, K. I., Zahrulakmal, M., Hahiree, M. K. I. M., Kendabie, P., Licea, L. C. S., Massawe, F., Mabhaudhi, T., Modi, A. T., Berchie, J. N., Amoah, S., Faloye, B., Abberton, M., Olaniyi, O., & Azam-Ali, S. N. (2019). Bambara Groundnut: An exemplar underutilised legume for resilience under climate change. *Planta*, *250*(3), 803–820. https://doi.org/10.1007/s00425-019-03191-6

Mayes, S., Massawe, F. J., Alderson, P. G., Roberts, J. A., Azam-Ali, S. N., & Hermann, M. (2012). The Potential for Underutilized Crops to Improve Security of Food Production. *Journal of Experimental Botany*, *63*(3), 1075–1079. https://doi.org/10.1093/jxb/err396

Mengxiao, Z. (2001). Crop Diversification in China. In *Crop Diversification in the Asia-Pacific Region* (pp. 24–31). FAO Regional Office for Asia and the Pacific.

Minnaar-Ontong, A., Gerrano, A. S., & Labuschagne, M. T. (2021). Assessment of genetic diversity and structure of Bambara Groundnut [*Vigna Subterranea* (L.) Verdc.] Landraces in South Africa. *Scientific Reports*, *11*(1), 7408. https://doi.org/10.1038/s41598-021-86977-7

Mohammed, I. Y., Abakr, Y. A., Hui, J. N. X., Alaba, P. A., Morris, K. I., & Ibrahim, M. D. (2017). Recovery of clean energy precursors from Bambara Groundnut waste via pyrolysis: Kinetics, products distribution and optimisation using response surface methodology. *Journal of Cleaner Production*, *164*, 1430–1445. https://doi.org/10.1016/j.jclepro.2017.07.068

Mubaiwa J., Fogliano V., Chidewe C., & Linnemann A. R. (2017). Hard-to-cook phenomenon in bambara groundnut [*Vigna Subterranea* (L.) Verdc.] processing: Options to improve its role in providing food security. *Food Reviews International*, *33*(2), 167–194. http://dx.doi.org/10.1080/87559129.2016.1149864

Murevanhema, Y. Y., & Jideani, V. A. (2013). Potential of Bambara Groundnut (*Vigna Subterranea* (L.) Verdc) Milk as a Probiotic Beverage—a Review. *Critical Reviews in Food Science and Nutrition*, *53*(9), 954–967.

Murevanhema, Y. Y., & Jideani, V. A. (2015). Production and characterization of milk produced from Bambara Groundnut (V Igna Subterranea) Varieties. *Journal of Food Processing and Preservation*, *39*(6), 1485–1498.

Nizar, M., Marahaini, N., Jahanshiri, E., Tharmandram, A. S., Salama, A., Sinin, S. S. M., Abdullah, N. J., Zolkepli, H., Wimalasiri, E. M., Suhairi, T. A. S. T. M., 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

Nwadi, O. M. M., Uchegbu, N., & Oyeyinka, S. A. (2020). Enrichment of food blends with Bambara groundnut flour: Past, present, and future trends. *Legume Science*, *2*(1), e25.

Okuofu, S. I., Gerrano, A. S., Singh, S., & Pillai, S. (2020). Deep Eutectic Solvent Pretreatment of Bambara Groundnut Haulm for Enhanced Saccharification and Bioethanol Production. *Biomass Conversion and Biorefinery*. http://dx.doi.org/10.1007/s13399-020-01053-w

Okwu, M., Samuel, O., & Emovon, I. (2018). Production of fuel briquettes from hybrid waste (blend of saw-dust and groundnut shell). *International Journal of Advanced Academic Research*, *6*(3), 1–14.

Oso, J. A., Edward, J. B., Ogunleye, O. A., & Majolagbe, F. A. (2013). Growth response and feed utilization of *Clarias Gariepinus* fingerlings fed with Bambara groundnut as protein Source. *Growth*, *3*(5), 84–90.

Otieno, M., Steffan-Dewenter, I., Potts, S. G., Kinuthia, W., Kasina, M. J., & Garratt, M. P. D. (2020). Enhancing legume crop pollination and natural pest regulation for improved food security in changing african landscapes. *Global Food Security*, *26*, 100394. https://doi.org/10.1016/j.gfs.2020.100394

People's Daily (2018). *China's rice, Soybean imports top the world in*. People's Daily.

Peter, B. G., Messina, J. P., Lin, Z., & Snapp, S. S. (2020). Crop climate suitability mapping on the cloud: A geovisualization application for sustainable agriculture. *Scientific Reports*, *10*(1), 15487. https://doi.org/10.1038/s41598-020-72384-x

Popkin, B. M. (2014). Synthesis and implications: China's nutrition transition in the context of changes across other low and middle income countries. *Obesity Reviews*, *5*(S1), 60–67. https://doi.org/10.1111/obr.12120

Popkin, B. M., & Du, S. (2003). Dynamics of the nutrition transition toward the animal foods sector in China and its implications: A worried perspective. *Journal of Nutrition*, *133*(11), 3898S–3906S. https://doi.org/10.1093/jn/133.11.3898S

Popkin, B. M., Keyou, G., Zhai, F., Guo, X., Ma, H., & Zohoori, N. (1993). The nutrition transition in China: A cross-sectional analysis. *European Journal of Clinical Nutrition*, *47*(5), 8319669.

Redjeki, E. S., Mayes, S., & Azam-Ali, S. (2011). Evaluating the stability and adaptability of Bambara groundnut (*Vigna Subterannea* (L.) Verd.) Landraces in Different Agro-Ecologies. II International Symposium on Underutilized Plant Species: Crops for the Future-Beyond Food Security, 979, 389–400.

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*, 12044. https://doi.org/10.1088/1755-1315/169/1/012044

Tan, X. L., Azam-Ali, S., Von Goh, E. E., Mustafa, M., Chai, H. H., Ho, W. K., Mayes, S., Mabhaudhi, T., Azam-Ali, S., & Massawe, F. (2020). Bambara groundnut: An underutilized leguminous crop for global food security and nutrition. *Frontiers in Nutrition*, *7*, 601496. https://doi.org/10.3389/fnut.2020.601496

The World Bank (n.d.). *Arable land China*. https://data.worldbank.org/indicator/AG.LND.ARBL.HA?locations=CN

Tian, H., Ren, W., Tao, B., Sun, G., Chappelka, A., Wang, X., Pan, S., Yang, J., Liu, J., Felzer, B. S., Mellilo, J. M., & Reilly, J. (2016). Climate extremes and ozone pollution: a growing threat to china's food security. *Ecosystem Health and Sustainability*, *2*(1), e01203. https://doi.org/10.1002/ehs2.1203

Tong, S., Berry, H. L., Ebi, K., Bambrick, H., Hu, W., Green, D., Hanna, E., Wang, Z., & Butler, C. D. (2016). Climate change, food, water and population health in China. *Bulletin of the World Health Organization*, *94*(10), 759–765. https://doi.org/10.2471/BLT.15.167031

Tong, Y., Niu, H., & Fan, L. (2016). Willingness of Farmers to transform vacant rural residential land into cultivated land in a major grain-producing area of central China. *Sustainability*, *8*(11), 1192. https://doi.org/10.3390/su8111192

Uchenna, C. J., & Omolayo, F. T. (2017). Development and quality evaluation of biscuits formulated from flour blends of wheat, Bambara nut and aerial yam. *Annals of Food Science and Technology*, *18*, 51–56.

van Dijk, M., Morley, T., Rau, M. L., & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, *2*(7), 494–501. https://doi.org/10.1038/s43016-021-00322-9

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., 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

Yang, J., Deng, Y., Chu, H., Cong, Y., Zhao, J., Pohl, D., Misselwitz, B., Fried, M., Dai, N., & Fox, M. (2013). Prevalence and Presentation of Lactose Intolerance and Effects on Dairy Product Intake in Healthy Subjects and Patients with Irritable Bowel Syndrome. *Clinical Gastroenterology and Hepatology*, *11*(3), 262–268. https://doi.org/10.1016/j.cgh.2012.11.034

Yang, X., Liu, Q., He, Y. I., Luo, X., & Zhang, X. (2016). Comparison of daily and sub-daily swat models for daily streamflow simulation in the upper huai river basin of China. *Stochastic Environmental Research and Risk Assessment*, *30*(3), 959–972. https://doi.org/10.1007/s00477-015-1099-0

Zhang, Z., & Changhe, L. U. (2020). Clustering analysis of soybean production to understand its spatiotemporal dynamics in the

North China Plain. *Sustainability*, *12*(15), 6178. https://doi.org/10.3390/su12156178
Zhou, S., Zhou, W., Lin, G., Chen, J., Jiang, T., & Li, M. (2017). Adapting to climate change: Scenario analysis of grain production in China. *China Agricultural Economic Review*, *9*(4), 643–659. https://doi.org/10.1108/CAER-10-2016-0173

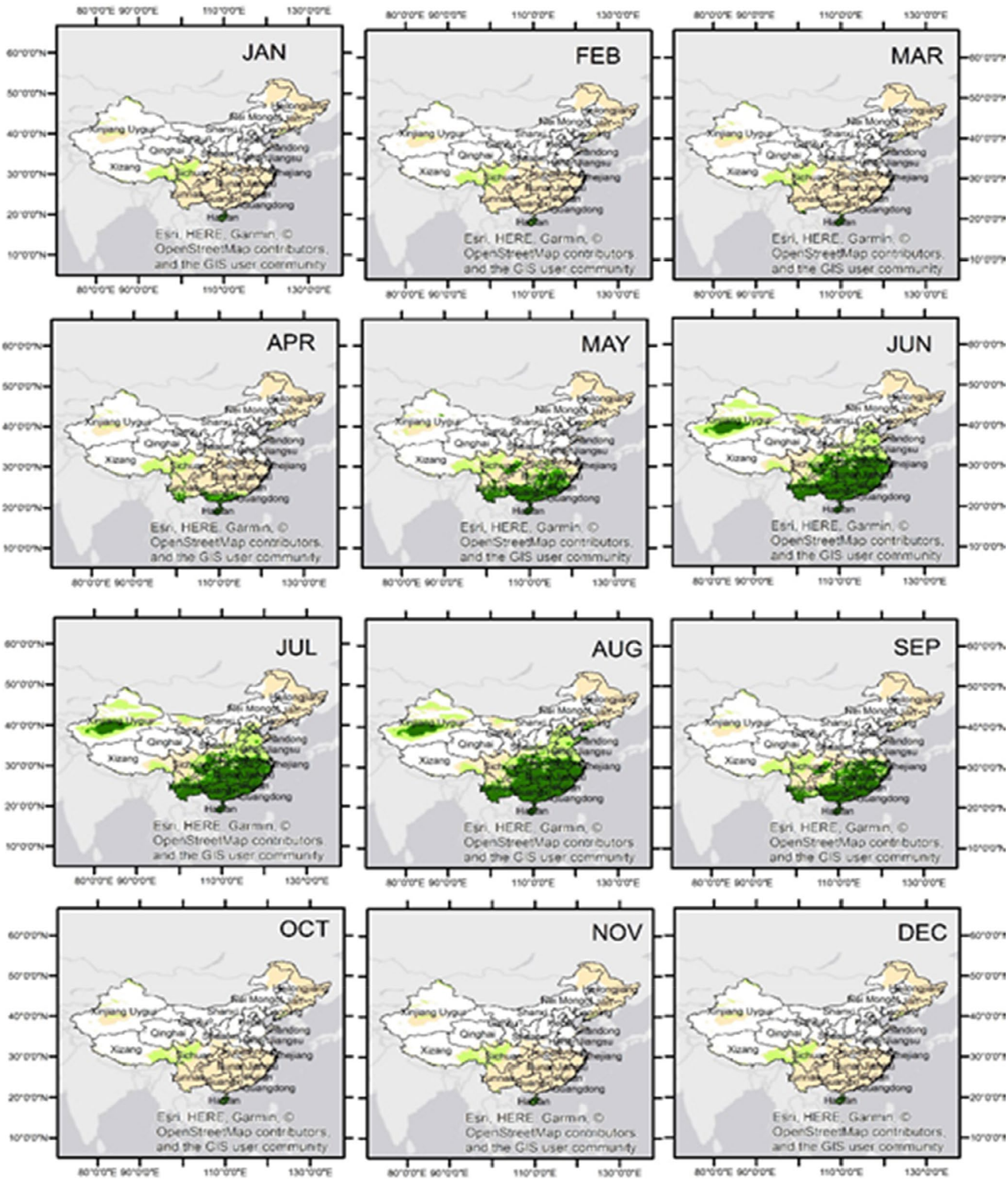
SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: 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*, 00, e358. https://doi.org/10.1002/fes3.358

APPENDIX 1

Seasonal suitability for Bambara groundnut in China



APPENDIX 2

Land statistics and potential production and income scenarios for Bambara groundnut

Administrative division	Irrigated area of cultivated land (ha) stats.gov.cn	Total Area of cultivated land (ha)stats.gov.cn	Remaining based on stats.go.cn	Land - S1	Production - S1	Protein - S1	Carbohydrate - S1	Income - S1
Anhui	4,580,800.00	5,866,800.00	1,286,000.00	608,944.51	517,602.83	108,696.60	326,089.79	74,017,205.19
Beijing	109,700.00	213,700.00	104,000.00	-	-	-	-	-
Chongqing	697,700.00	2,369,800.00	1,672,100.00	5,220,259.00	4,437,220.15	931,816.23	2,795,448.69	634,522,481.45
Fujian	1,076,800.00	1,336,900.00	260,100.00	432,621.15	367,727.98	77,222.88	231,668.63	52,585,100.78
Gansu	1,328,900.00	5,377,000.00	4,048,100.00	-	-	-	-	-
Guangdong	1,773,400.00	2,599,700.00	826,300.00	2,300,169.56	1,955,144.13	410,580.27	1,231,740.80	279,585,610.02
Guangxi	1,713,100.00	4,387,500.00	2,674,400.00	4,269,365.28	3,628,960.49	762,081.70	2,286,245.11	518,941,349.78
Guizhou	1,154,000.00	4,518,800.00	3,364,800.00	8,943,041.22	7,601,585.04	1,596,332.86	4,788,998.57	1,087,026,660.29
Hainan	290,600.00	722,400.00	431,800.00	740,436.04	629,370.63	132,167.83	396,503.50	90,000,000.66
Hebei	4,482,200.00	6,518,900.00	2,036,700.00	-	-	-	-	-
Heilongjiang	6,177,600.00	15,845,700.00	9,668,100.00	-	-	-	-	-
Henan	5,328,900.00	8,112,300.00	2,783,400.00	590,609.08	502,017.72	105,423.72	316,271.16	71,788,533.67
Hubei	2,969,000.00	5,235,900.00	2,266,900.00	4,043,040.84	3,436,584.71	721,682.79	2,165,048.37	491,431,614.10
Hunan	3,176,100.00	4,151,000.00	974,900.00	10,642,766.35	9,046,351.40	1,899,733.79	5,699,201.38	1,293,628,249.84
Nei Mongol	3,199,200.00	9,270,800.00	6,071,600.00	28,944.61	24,602.92	5,166.61	15,499.84	3,518,217.35
Jiangsu	4,205,400.00	4,573,300.00	367,900.00	6,540,794.15	5,559,675.03	1,167,531.76	3,502,595.27	795,033,528.93
Jiangxi	2,036,100.00	3,086,000.00	1,049,900.00	-	-	-	-	-
Jilin	1,909,500.00	6,986,700.00	5,077,200.00	-	-	-	-	-
Liaoning	1,629,200.00	4,971,600.00	3,342,400.00	-	-	-	-	-
Ningxia Hui	538,300.00	1,289,900.00	751,600.00	-	-	-	-	-
Qinghai	213,300.00	590,100.00	376,800.00	-	-	-	-	-
Shaanxi	1,285,200.00	3,982,900.00	2,697,700.00	196,473.38	167,002.37	35,070.50	105,211.49	23,881,339.34
Shandong	5,271,400.00	7,589,800.00	2,318,400.00	27,488.46	23,365.19	4,906.69	14,720.07	3,341,222.31
Shanghai	190,800.00	191,600.00	800.00	-	-	-	-	-
Shanxi	1,519,300.00	4,056,300.00	2,537,000.00	-	-	-	-	-
Sichuan	2,954,100.00	6,725,200.00	3,771,100.00	2,646,940.85	2,249,899.72	472,478.94	1,417,436.83	321,735,660.32
Tianjin	304,800.00	436,800.00	132,000.00	-	-	-	-	-
Xinjiang Uygur	4,959,900.00	5,239,600.00	279,700.00	-	-	-	-	-
Xizang	275,900.00	444,000.00	168,100.00	-	-	-	-	-
Yunnan	1,922,500.00	6,213,300.00	4,290,800.00	6,785,923.08	5,768,034.62	1,211,287.27	3,633,861.81	824,828,950.37
Zhejiang	1,405,400.00	1,977,000.00	571,600.00	1,490,380.97	1,266,823.82	266,033.00	798,099.01	181,155,806.90
SUM	68,679,100.00	134,881,300.00	66,202,200.00	55,508,198.53	47,181,968.75	9,908,213.44	29,724,640.31	6,747,021,531.32

Administrative division	Land - S2	Production- S2	Protein- S2	Carbohydrate - S2	Income - S2	Land - S3	Production- S3	Protein- S3	Carbohydrate - S3	Income - S3
Anhui	1,014,907.52	862,671.39	181,160.99	543,482.98	123,362,009.06	1,971,820.32	1,676,047.27	351,969.93	1,055,909.78	239,674,759.90
Beijing	26,196.87	22,267.34	4,676.14	14,028.42	3,184,229.55	654,921.84	556,683.56	116,903.55	350,710.65	79,605,749.65
Chongqing	5,724,488.56	4,865,815.28	1,021,821.21	3,065,463.62	695,811,584.47	5,813,470.25	4,941,449.71	1,037,704.44	3,113,113.32	706,627,308.89
Fujian	432,621.15	367,727.98	77,222.88	231,668.63	52,585,100.78	432,621.15	367,727.98	77,222.88	231,668.63	52,585,100.78
Gansu	28,067.63	23,857.49	5,010.07	15,030.22	3,411,620.43	140,338.13	119,287.41	25,050.36	75,151.07	17,058,099.70
Guangdong	2,300,169.56	1,955,144.13	410,580.27	1,231,740.80	279,585,610.02	2,300,169.56	1,955,144.13	410,580.27	1,231,740.80	279,585,610.02
Guangxi	4,269,365.28	3,628,960.49	762,081.70	2,286,245.11	518,941,349.78	4,269,365.28	3,628,960.49	762,081.70	2,286,245.11	518,941,349.78
Guizhou	9,429,737.34	8,015,276.74	1,683,208.12	5,049,624.35	1,146,184,573.68	9,703,503.91	8,247,978.32	1,732,075.45	5,196,226.34	1,179,460,900.26
Hainan	740,436.04	629,370.63	132,167.83	396,503.50	90,000,000.66	740,436.04	629,370.63	132,167.83	396,503.50	90,000,000.66
Hebei	925,771.18	786,905.50	165,250.16	495,750.47	112,527,486.93	9,442,866.00	8,026,436.10	1,685,551.58	5,056,654.74	1,147,780,362.30
Heilongjiang	-	-	-	-	-	-	-	-	-	-
Henan	956,224.22	812,790.59	170,686.02	512,058.07	116,229,053.94	5,090,487.76	4,326,914.60	908,652.07	2,725,956.20	618,748,787.23
Hubei	6,492,474.34	5,518,603.19	1,158,906.67	3,476,720.01	789,160,256.03	7,554,879.23	6,421,647.35	1,348,545.94	4,045,637.83	918,295,570.41
Hunan	11,580,055.43	9,843,047.12	2,067,039.89	6,201,119.68	1,407,555,737.52	11,731,231.09	9,971,546.43	2,094,024.75	6,282,074.25	1,425,931,138.99
Nei Mongol	260,501.50	221,426.28	46,499.52	139,498.55	31,663,957.33	752,559.89	639,675.91	134,331.94	402,995.82	91,473,654.63
Jiangsu	6,540,794.15	5,559,675.03	1,167,531.76	3,502,595.27	795,033,528.93	6,540,794.15	5,559,675.03	1,167,531.76	3,502,595.27	795,033,528.93
Jiangxi	-	-	-	-	-	-	-	-	-	-
Jilin	51,357.52	43,653.89	9,167.32	27,501.95	6,242,506.56	616,290.20	523,846.67	110,007.80	330,023.40	74,910,073.81
Liaoning	-	-	-	-	-	-	-	-	-	-
Ningxia Hui	-	-	-	-	-	-	-	-	-	-
Qinghai	-	-	-	-	-	338,167.43	287,442.32	60,362.89	181,088.66	41,104,251.12
Shaanxi	1,178,840.29	1,002,014.25	210,422.99	631,268.98	143,288,037.25	3,452,317.99	2,934,470.29	616,238.76	1,848,716.28	419,629,251.68
Shandong	3,106,195.54	2,640,266.21	554,455.90	1,663,367.71	377,558,067.89	12,809,620.54	10,888,177.46	2,286,517.27	6,859,551.80	1,557,009,376.64
Shanghai	-	-	-	-	-	-	-	-	-	-
Shanxi	-	-	-	-	-	2,116,118.78	1,798,700.96	377,727.20	1,133,181.61	257,214,237.71
Sichuan	4,499,799.44	3,824,829.52	803,214.20	2,409,642.60	546,950,621.93	12,146,517.45	10,324,539.83	2,168,153.36	6,504,460.09	1,476,409,196.05
Tianjin	-	-	-	-	-	978,672.39	831,871.53	174,693.02	524,079.06	118,957,629.00
Xinjiang Uygur	-	-	-	-	-	114,606.03	97,415.13	20,457.18	61,371.53	13,930,362.95
Xizang	-	-	-	-	-	970,544.98	824,963.23	173,242.28	519,726.84	117,969,742.32
Yunnan	8,985,925.54	7,638,036.71	1,603,987.71	4,811,963.13	1,092,239,249.39	10,442,265.20	8,875,925.42	1,863,944.34	5,591,833.01	1,269,257,335.06
Zhejiang	1,490,380.97	1,266,823.82	266,033.00	798,099.01	181,155,806.90	1,490,380.97	1,266,823.82	266,033.00	798,099.01	181,155,806.90
SUM	70,034,310.07	59,529,163.56	12,501,124.35	37,503,373.04	8,512,670,389.01	112,614,966.56	95,722,721.58	20,101,771.53	60,305,314.59	13,688,349,185.37

Administrative division	Land - S4	Production- S4	Protein- S4	Carbohydrate - S4	Income - S4
Anhui	1,286,000.00	1,093,100.00	229,551.00	688,653.00	156,313,300.00
Beijing	104,000.00	88,400.00	18,564.00	55,692.00	12,641,200.00
Chongqing	1,672,100.00	1,421,285.00	298,469.85	895,409.55	203,243,755.00
Fujian	260,100.00	221,085.00	46,427.85	139,283.55	31,615,155.00
Gansu	4,048,100.00	3,440,885.00	722,585.85	2,167,757.55	492,046,555.00
Guangdong	826,300.00	702,355.00	147,494.55	442,483.65	100,436,765.00
Guangxi	2,674,400.00	2,273,240.00	477,380.40	1,432,141.20	325,073,320.00
Guizhou	3,364,800.00	2,860,080.00	600,616.80	1,801,850.40	408,991,440.00
Hainan	431,800.00	367,030.00	77,076.30	231,228.90	52,485,290.00
Hebei	2,036,700.00	1,731,195.00	363,550.95	1,090,652.85	247,560,885.00
Heilongjiang	9,668,100.00	8,217,885.00	1,725,755.85	5,177,267.55	1,175,157,555.00
Henan	2,783,400.00	2,365,890.00	496,836.90	1,490,510.70	338,322,270.00
Hubei	2,266,900.00	1,926,865.00	404,641.65	1,213,924.95	275,541,695.00
Hunan	974,900.00	828,665.00	174,019.65	522,058.95	118,499,095.00
Nei Mongol	6,071,600.00	5,160,860.00	1,083,780.60	3,251,341.80	738,002,980.00
Jiangsu	367,900.00	312,715.00	65,670.15	197,010.45	44,718,245.00
Jiangxi	1,049,900.00	892,415.00	187,407.15	562,221.45	127,615,345.00
Jilin	5,077,200.00	4,315,620.00	906,280.20	2,718,840.60	617,133,660.00
Liaoning	3,342,400.00	2,841,040.00	596,618.40	1,789,855.20	406,268,720.00
Ningxia Hui	751,600.00	638,860.00	134,160.60	402,481.80	91,356,980.00
Qinghai	376,800.00	320,280.00	67,258.80	201,776.40	45,800,040.00
Shaanxi	2,697,700.00	2,293,045.00	481,539.45	1,444,618.35	327,905,435.00
Shandong	2,318,400.00	1,970,640.00	413,834.40	1,241,503.20	281,801,520.00
Shanghai	800.00	680.00	142.80	428.40	97,240.00
Shanxi	2,537,000.00	2,156,450.00	452,854.50	1,358,563.50	308,372,350.00
Sichuan	3,771,100.00	3,205,435.00	673,141.35	2,019,424.05	458,377,205.00
Tianjin	132,000.00	112,200.00	23,562.00	70,686.00	16,044,600.00
Xinjiang Uygur	279,700.00	237,745.00	49,926.45	149,779.35	33,997,535.00
Xizang	168,100.00	142,885.00	30,005.85	90,017.55	20,432,555.00
Yunnan	4,290,800.00	3,647,180.00	765,907.80	2,297,723.40	521,546,740.00
Zhejiang	571,600.00	485,860.00	102,030.60	306,091.80	69,477,980.00
SUM	66,202,200.00	56,271,870.00	11,817,092.70	35,451,278.10	8,046,877,410.00