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RESEARCH ARTICLE

Efforts for the Revival of *Vigna subterranea* (L.) Verdc. (Bambara groundnut) through Germplasm Introduction in India

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Abstract

Vigna subterranea (L.) Verdc. (Bambara groundnut), an underutilized leguminous crop was studied with respect to plant morphology, prospects of crop introduction, and application of climatic analogues tools (CAT) to identify the most suitable areas for cultivation in India. Data on regular introductions of the crop in India was presented and the lack of information on crop performance in multi-location trials were the major gaps that need special attention in the Indian context. This paper attempts on some preliminary morphological observations under field trials and application of CAT besides botany, methods of propagation, use, and cultivation practices.

Keywords: Climate analogs tools, Crop introduction, *Vigna subterranea*.

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Introduction

Vigna subterranean (L.) Verdc. (family Leguminosae/Fabaceae) is among the most of the African crop species viz. groundnut (*Arachis hypogaea* L.), cowpea (*Vigna unguiculata* L.) that have contributed towards food, nutritional, and health security for humankind (Alhassan and Egbe, 2013). It is commonly known by several names- Bambara groundnut, Bambara bean, Bambara nut, hog-peanut, ground-bean earth pea, etc. Bambara groundnut is related to cowpea (*Vigna unguiculata*) and desires the same niche as the groundnut (*Arachis hypogaea* L.). The taxon seed is closer to chickpea (*Cicer arietinum*) (Halimi et al. 2019). The crop is extensively grown the sub-Saharan region of West Africa where it is considered as the third most important grain legume (Muhammad *et al*., 2020; Tan *et al*., 2020).

The sub-Saharan African warm tropical regions are the areas where bambara groundnut is mostly cultivated (Bamshaiye et al. 2011; Hillocks *et al*., 2012). Despite its drought-tolerant trait, it remains an underutilized legume only as a subsistence crop. In recent years bambara groundnut has attained the status of "wonder crop" due to its rich genetic diversity and potential in climate change regime (Muhammad *et al*., 2020).

The primary centre of diversity for bambara groundnut is in the north-eastern part of Nigeria and northern Cameroon. It is an underutilized legume assuming the status of nutritionally rich crops (Halimi *et al*., 2019) with high potential as biofertilizer in parts of Thailand and Indonesia. The crop is highly tolerant to biotic and abiotic stress condition such as drought, pests, diseases and well adapted to nutritionally poor soils and thus can secure production under climate change regime. There is an extensive genetic variation in bambara groundnut for several agronomic characteristics and there is scope for improvement through breeding, value addition and marketing. The landraces of bambara groundnut are highly variable in seed testa colour and taste ranging from cream to white based on consumer preferences. Uba *et al*. (2021) have identified different landraces sub-population from different geographical regions. The seeds are a source of cheap and good quality protein and have been a food resource for poor people residing in semi-arid regions (Okonkwo and Opara, 2010; Tan *et al.* 2020). Since its introduction in many parts of the globe, the crop has gained significant consideration by the scientific and financial institutions at international levels but been largely ignored by the research community (Oyeyinka *et al*., 2015) probably due to low prioritization crop at the institute level, poor policy decisions on crop implementation, acceptance by the farmers, non-availability of agronomic practices for crop cultivation (Hillocks *et al*., 2012; Feldman *et al*., 2019).

Subsequent upon introduction of bambara groundnut in India long back, research trials were conducted in several agro-climatic zones of the country. In recent efforts by the Indian Council of Agricultural Research (ICAR), National Bureau of Plant Genetic Resources (NBPGR), New Delhi ten accessions of bambara groundnut were introduced from Mali for adaptation trials under the collaborative programme on "Evaluation of Stress Tolerant Orphan Legumes (STOL) for Use in Dryland Farming Systems across Sub-Saharan Africa and India".

This paper attempts to report results of a preliminary experimental study on introduced germplasm of bambara groundnut from Mali to adaptation trials and use of climatic analogues to identify most suitable areas of crop introduction. Also information on potential uses of the crop, botany and propagation, cultivation etc. are provided with the perspective on recent research progress evaluating for future breeding in the Indian context.

Materials and Methods

Experiment and Planting Material

All 10 accessions of bambara groundnut imported from Mali were grown in *Kharif* 2020-21 at the NBPGR Pusa farm located in New Delhi. Preliminary morphological and evaluation data were recorded using selected accessions- EC1036859, EC1036855, EC1036861, EC1036862, EC1036853, EC1036854, EC1036860, EC1036857, EC1036858 and EC1036856. Data on various selected parameters were recorded for plants sown in a row of 2 m in length as per the available descriptors (IPGRI, IITA, BAMNET, 2000).

Data on previous introductions made in bambara groundnut in India were drawn from the records maintained in the Germplasm Exchange and Policy Unit located at the ICAR-NBPGR, New Delhi. The climatic analogues data were gathered from areas of global cultivation and their equivalent climatic analogues zones in India and cast as sites of probable successful introduction in India. The climate gradient maps were casted based on data from literature survey, and climatic variables (*Worldclim.com*) and DIVA-GIS interfaced with climate data for precipitation and temperature gradients (Hijmans *et al*., 2007; Semwal *et al*., 2021). Information on botany, cultivation, propagation and uses were drawn through the literature available on the current status of crop in India and personal interaction with the indenters.

Result and Discussion

Morphological Observations

The bambara groundnut, an annual, is a short, creeping herb with a habit of bunchy and semi-bunchy form. The terminal leaflet is oval-shaped, measured from 5.1-6.4 x 1.8–2.1 cm, and the stem is densely pubescent. Usually, the petiole is longer than the leaflet and measured from 10-12.1 cm. The flower was mostly yellow (Fig. 1), measured from 0.8–1.3 cm. Vertical stripes are found in the standard petal (SP). After pollination, white coloured peg formation was initiated under the soil. Variation was recorded in mature pods from yellowish-reddish-brown (little grooves) ranging from 0.5–1.5 x 0.3–0.9 cm; seed variation was recorded for coat colour from cream (dark-red butterfly-like eye spots) to cream (black triangular eye-spot), 100 seed weight from 20–57 g and seed size from 0.5–1.1 cm.

Botany, Plant Propagation and Crop Production

The pods formation is alike peanut where pods develop underground; each pod has 1–2 seeds of round or unilaterally flattened shape with smooth hard seed coat, nearly 1.6 cm diameter, colour ranging from white, cream or brown, red, mottled and black. The plant needs a temperature in between 30–40°C at the time of flowering. The species is predominantly self-pollinated with cleistogamous flowers; flowering occurs in 40 to 60 days after planting. However, there are reports on generative autogamous (self-fertilization) and cleistogamous (self-pollinating) reproduction (Chandra *et al*., 2020) of the species. The plant has 90 to 170 days growth cycle; pod maturity after 30 days of pollination.

Bambara groundnut in the Sahara region of Africa is an important food crop that grows successfully on diverse types of soil under hot, humid, cool climate (Temegne *et al*., 2018). The crop is suitable for marginal soils and well adaptable to high temperatures.

The landraces of bambara groundnut are year old selections and culturally raised as solo crop or under intercropping with maize, millets, sorghum, peanut, yams, cassava, etc. having drought tolerance (Zeven,1998; Olayide *et al*., 2018). The yield (t ha^{-1}) is variable among the landraces and areas of cultivation (Begemann, 1988). Over a period of more than three decades, the bambara groundnut world production has increased several folds and now amounting to 0.23 million tonnes annually in 2020 with a yield of 649.9 kg/ha (FAOSTAT, 2022).

Crop Introduction in India: Efforts in the Past

Bambara groundnut grows in all agro-climatic conditions where groundnut (*Arachis hypogea*; peanut) is cultivated (Singh *et al*., 2020). In the Indian context a, limited research progress has been observed despite of its repeated introduction five decades back. Efforts were made to introduce *Vigna subterranea* in many Asian countries with identical agro-climatic conditions. This species was introduced to India and desirable germplasm was diffused to the indenters for research requirements. Analysis of the preliminary records on the exchange of the germplasm suggested that introductions trial for diverse seeded types in bambara groundnut were attempted in India as early as 1949 from parts of East Africa. Subsequent introductions were made in 1950, 1953, and 1957 from Australia, the Department of Agriculture, Mauritius and others (Table 1). In 2019, under the exchange program by the ICAR-NBPGR fresh introductions from Mali were made for research under STOL project.

In literature, bambara groundnut is frequently reported under cultivation in tropical Central and South America, the Philippines, South Pacific, Australia and Papua New Guinea, southeast Asia India, Sri Lanka, Malaysia and Indonesia and grouped under the "secondary centre of diversity outside Africa" (Duke 1982; NAS 1979; Nwokolo 1996; Majola *et al.* 2021). Scrutiny of the Indian literatures as well as personal interaction with scientists working on crop confirmed that except the experimental cultivation, the crop had never been in public domain. However, reports on adaptive studies during the initial phase of the crop introduction in the country confirm experimental studies (Gowda and Krishnan 1968; Sanjappa 2010).

Studies on Adaptive Trials

A total of 12 varieties of bambara groundnut were tested in a replicated trial in Bhubaneswar, Odisha. Trial data revealed

Table 1: Import of bambara groundnut (*Vigna subterranea*) in India

EC No.	*(year)*	*Source*
EC1765-9	(1949)	East Africa (through Commission B.E.A)
EC1946	(1950)	Australia
EC4969	(1953)	Dept. of Agriculture, Ministry of Agro-Industry and Food Security Agricultural services, Reduit, Mauritius
EC12317-30	(1957)	Ministry of Agri., Shambat, Sudan
EC27879-81	(1964)	University College of Ghana , Achimota, ACCRA Ghana
EC37782-5	(1966)	ShefSecteur, Agricule, Cenbio, IRAI, BP-6, MARAD, NIGER
EC38245-50	(1966)	Dept. of Agriculture, Kampala, Uganda
EC38886-91	(1967)	The Director, IRAI, Senegal
EC42581-5	(1967)	Causeway, Salbury Rhodesia
EC100046-50	(1972)	Crops Research Institute, Bunso-Bosuso, Ghana
EC116163-164	(1976)	Rothamsted, England,
EC132769-770	(1980)	Mali
EC134501- 84		Nigeria
EC138348-53	(1980)	Agronomy Institute causeway, Zimbabwe
EC155891-2	(1983)	USDA-ARS Regional Plant Introduction Station, Georgia, USA
EC159150	(1984)	USDA-ARS Regional Plant Introduction Station, Georgia, USA
EC173345- 54	(1985)	Zimbabwe
EC191543- 7	(1986)	ICRISAT, Patancheru
EC240614-15	(1988)	UK
EC388662	(1996)	USDA-ARS, Beltsville, MD, USA
EC508312- 21	(2002)	Division of Agricultural Sciences, Leicestershire, UK
EC571836- EC571841	(2006)	Division of Agricultural Sciences, Leicestershire, UK
EC612805-806	(2008)	Ghana
EC698896- 8983	(2011)	IITA, Nigeria
EC1036853-58, 60-62	(2019)	Mali

that the range of variation was 53–59 for 50% flowering; 10.7–28 for plant stand at harvest, 34.4–38.2 cm for plant height; 11.6–26.6 for pods per plant and 0.62–2.69 q/ha for yield. Highest yield was in EC38245, followed by EC134535 (2.26 q/ha), EC37527 (2.13 q/ha) and EC134507 (2.01 q/ha) (Annual Report 1990-91).

Research attempts were made by ICAR-Directorate of Groundnut Research (formerly known as National Research Centre for Groundnut, NRCG), Junagarh, Gujarat, India to screen landraces of bambara groundnut for drought tolerance stress genes and for use in improvement in the groundnut. Singh and Basu (2006) while working on the physiology of bambara groundnut showed that the crop performance in Gujarat (western India) under a semi-arid climate and *kharif* season with early July sowing was most satisfactory. During the study three high-yielding genotypes DODR-TZ, SB 4-2 and S19-3 with 117-133 days maturity period and two short duration genotypes- AS-17, and S19-3 were identified. These were further tested in the Rajasthan, Maharashtra and Gujarat where the length of growing period was short.

Research studies undertaken in collaborative mode with NRCG, Junagarh, Gujarat; CAZRI, Judhpur; RRS Bikaner, Rajasthan and University of Agricultural Sciences, Bangalore have suggested this crop can grow well in arid and semi-arid zones of Gujarat, Rajasthan and part of Andhra Pradesh (Bannayan *et al*., 2000). Recent research initiatives of the ICAR under a collaborative programme entitled "Evaluation of Stress Tolerant Orphan Legumes (STOL) for use in dryland farming systems across sub-Saharan Africa and India- Promoting India-Africa Framework for Strategic Cooperation" resulted in the introduction of 10 accessions of very distinct germplasm and varietal material with a partnership with the Kirkhouse Trust (KT). The germplasm has been under detailed evaluation study at NBPGR, New Delhi, since 2020.

Use of Climatic Analogues Tools (CAT)

Reduced and erratic global rainfall has adversely affected the agricultural systems (IPCC 2014; Padulosi *et al*. 2011; Mayes *et al*. 2019) that has led to the identification of crops like bambara groundnut which can provide nutritional and food security. Production of bambara groundnut needs optimal temperature between 19–30°C, minimal annual rainfall about 300 mm and optimal annual rainfall between 750–1400 mm.

Success of introduced germplasm is assessed by the effective response of species performance under new environments and areas of better adaptation. In the present study, the crop analogue sites (called reference sites) were identified with help of Climate Analogue Tool (CAT) tools. Identification of suitable analogue sites for developed varieties and newly introduced germplasm based on the characteristics of the site is possible through CAT application (Mubaiwa *et al*., 2018).

Bannayan *et al*. (2000) undertook field studies and suggested areas in Gujarat (Western India) and Andhra Pradesh (Southern India) for multi-locational testing and release of promising accessions in India. Study resulted in identification of suitable sites in different states (districts in parenthesis) in the country through climatic gradient data from the sites of cultivation superimposed on the similar sites in the Indian region were drawn and - Gujarat Krishnagiri, Dharmapuri, Salem, Villupuram) (Figure 1 and 2). Field studies and adaptive trials on the bambara groundnut identified potential in semi-arid tropics of India with moderate suitability for cultivation of bambara groundnut (Singh and Basu, 2006).

Bambara groundnut popularization and commercialization will be based on the nutritional aspects and its performance in different areas. Government intervention and networking through AICRN on potential crops has to play a pivotal role in multi-locational trials in most suitable areas and has to come up with packages of practice for this crop.

Uses

In India, bambara groundnut is still in the trial stage. The crop is extensively used in African regions in roasted form, as a snack, processed into cake, in boiled form.

The flour is suitable for preparing cakes, puddings, bread, etc. A delicacy, "Okpa", known from South Eastern

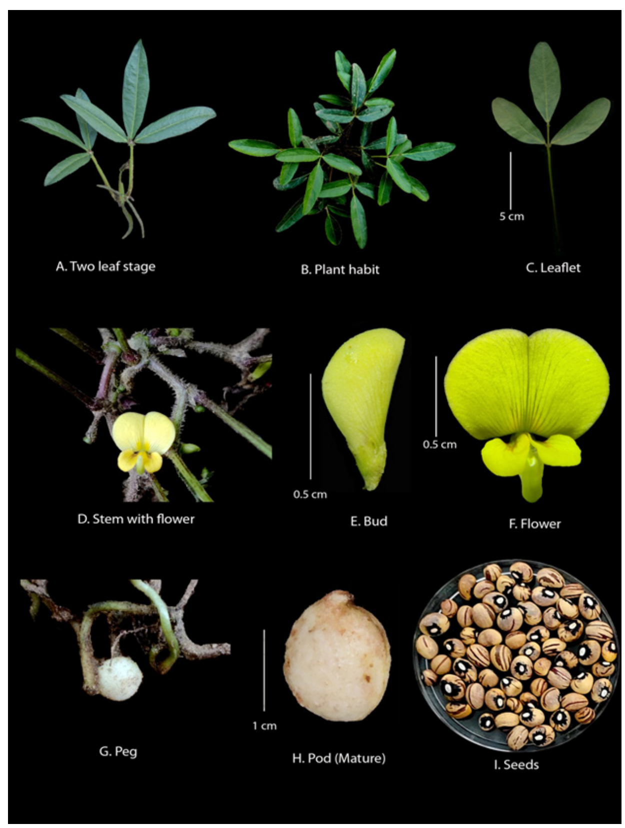

Figure 1: Depiction of vegetative and reproductive parts of of bambara groundnut.

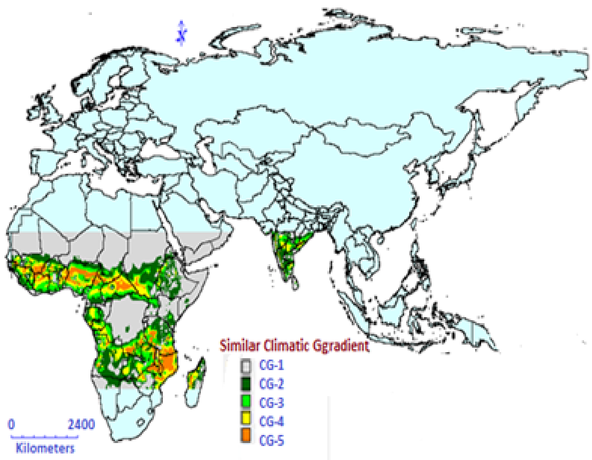

Figure 2: Climatic analogous sites (African continent) identified with current climate of Indian states, indicating potential options for exchange of bambara: CG-1-Climate gradient -1(unsuitable); CG-2-Climate gradient -2 (low suitable); CG-3-Climate gradient -3 (medium suitable); CG-4-Climate gradient -4 (high suitable); CG-5-Climate gradient -5 (very high suitable).

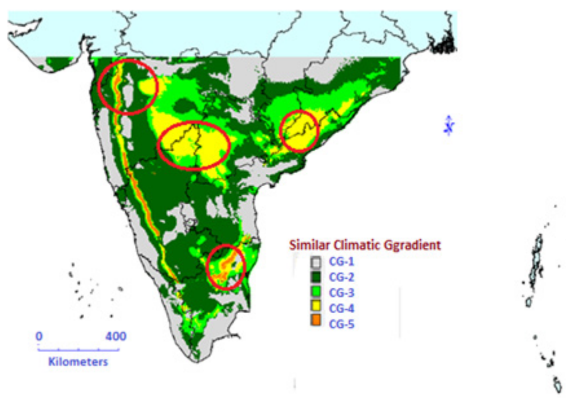

Figure 3: Climatic analogous sites with the current climate of Indian states, indicating potential options for exchange of bambara groundnut: CG-1-Climate gradient-1 (unsuitable); CG-2-Climate gradient-2 (low suitable); CG-3-Climate gradient -3 (medium suitable); CG-4-Climate gradient -4 (high suitable); CG-5-Climate gradient -5 (very high suitable shown with circles).

Nigeria, is prepared using finely powdered beans of bambara groundnut mixed with palm oil, water and pumpkin leaves turned into a paste and then boiled after wrapping into banana leaf.

Conclusions

The bambara groundnut could provide quality plant proteins and has great potential for use in various forms as human diet, especially in climate change-ready agriculture where other protein-rich crops may not perform well. However, the crop is under-researched and under-utilized in many parts of the globe; data on yield, proper package of practices, application of nutrients and improvement of the nitrogen-fixing capacity and studies on crop phenology are meager. India looks forward with the possibility of bambara groundnut as an important resource for plant genetic resources.

New generations of bambara groundnut cultivars should comprise of market preference, including desirable agronomic, nutritional, and processing qualities that benefit the food and feed industry. The study brings out the following bottleneck points that emerge in the Indian context:

- Data on performance and pre-evaluation trials in public domain to facilitate gaps and thrust in genetic improvement of the crop.
- Information on the genetic diversity, drought tolerance, and nutrient contents of diverse collections.
- Conducting multi-location trials through All India Coordinated Research Project and performance and most suitable growing period.
- Availability of diverse germplasm in global genebanks for future research and developments.
- Adaptive trials after using CAT tools.

Like other under-utilised crops, unsuitability of Bambara groundnut as food due to hardness of seed and 'photoperiod sensitivity to pod filling' are associated with the crop use and deserve to be thrusts in breeding programmes. This crop deserves its prime role in broadening India's food basket base. The authors are engaged in further studies under evaluation programme at the NBPGR, New Delhi.

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