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Phenotypic characterization of the exotic Genotypes and widely cultivated common bean Genotypes in Southern Highlands of Tanzania

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ABSTRACT

Common bean (Phaseolus vulgaris L.) is a key legume crop that is prized for its nutrition, adaptability, and ability to promote sustainable agriculture through nitrogen fixation. In Tanzania southern highlands, common bean characterization creates limitations to its potential yield and responsiveness to varying environments. In this research, phenotypic characterization of 12 popular common bean genotypes in southern highlands of Tanzania and imported genotypes from CIAT Colombia were studied. In the evaluation, promising genotypes with desirable phenotypic characteristics were identified. The genotype 22ACC02333 was characterized by strong growth and heavy leaf intensity, 22ACC03221 were characterized by medium-sized leaves and heavy curvature of pods, 22ACC02881 was characterized by pale green leaves with pigmented stems, and 22ACC02433 was characterized by spreading growth and twining habit. All the above genotypes shown favorable phenotypic characters of flowers, yielding, testa color, and heavy growing structure, indicating their suitability for future breeding programs. The study highlighted the market worth of such genotypes since they complied with market requirements for the uniformity of pod size, seed pigmentation, storage capacity, and yield potential, making them suitable for consumer and processing uses. Further, the phenotypic characteristics scored for these genotypes rate them with ability to withstand against biotic and abiotic stress which are vital for small scale farmers' common bean production in the regions. The study is a strategic manual to breeding programs seeking to develop better productive, resistant and marketable improved varieties that are valued materials for viable agriculture development across Tanzania's southern highlands and other areas affected by climate variability.

Keywords: Breeding, Genotypes, Characterization, Genetic Diversity, Phenotype.

1. INTRODUCTION

Common bean (*Phaseolus vulgaris L.*) is a globally popular legume, highly regarded for its abundant protein, dietary fiber and vital micronutrients such as iron and zinc [1]. It serves as a staple food across Asia, Latin America, and Africa, holding unmatched importance compared to other leguminous crops [2]. Apart from its micronutrient gratified, the common bean has gigantic quantities of bioactive combinations of bio-compounds such as phenolic acids and antioxidants that have imparted to it several health benefits from reducing the risk of human body diseases [1],[2]. Distinctly from its nutritive quality, the common bean is at the center of viable agriculture owed to its capacity to fix nitrogen in the air, improve soil fertility, and lessen dependency on inorganic fertilizers [3]. Its ability to thrive in diverse agro-ecological environments, along with its exceptional nutritional value, positions it as a key element in contemporary agricultural practices [4].

In Tanzania, the common bean is an agriculturally and culturally valuable crop, especially in the southern highland, which has high common bean germplasm diversification [5]. The country's germplasm, as molded by business trends and heterogeneous ecology and climatic conditions, has genetic input from both the Andean and Mesoameric gene pools [6]. Production is principally concentrated in Mbeya and Songwe districts, where varieties like Selian 13, Njano Uyole, Uyole 16, Lyamungo 90, Kablanket and Calima Uyole are highly prized for their excellent agronomic traits and substantial market demand [6] [7]. These varieties listed are well adapted to specific microclimates, included in conventional farming systems, where are mostly intercropped with maize, bananas, and coffee under rain-fed cropping [7]. Despite their rich genetic foundation, the insufficient phenotypic characterization in modern farming techniques has led to a decline in productivity, making these varieties more vulnerable to both biotic and abiotic stress factors [8]. The Tanzania Agricultural Research Institution highly advocates for improved common bean varieties that exhibit high productivity and resilience to both biotic and abiotic stress. These enhanced types play a crucial role in conserving genetic resources while advancing breeding programs focused on boosting yields, enhancing stress tolerance, and strengthening common bean disease resistance [9].

2. LITERATURE REVIEW

The common bean (*Phaseolus vulgaris L.*) is a vital legume with potential cultivation in Tanzania's southern highlands zone where the zone is listed among the big four in terms of common bean production in the country [10]. It stands as the second most significant dietary protein source for humans and the third most important crop for caloric intake in Eastern and Southern Africa [10], [11]. The common bean has its origins in two primary gene pools, the Andean and Mesoamerican, arising through successive domestication events within the species. The majority of its genetic variation is preserved ex-situ outside it is original regions in genebanks [11]. Improved and traditional varieties contribute significantly in breeding in Tanzania towards the production of high-yielding and durable crops capable of withstanding biotic and abiotic stresses [12]. Genetic diversity knowledge, identification, and characterization of genotypes, and discrimination between variations is vital in the identification of duplicate accessions in collections, which ultimately leads to the establishment of the core collections in gene banks [13]. The process also facilitates the identification of accessions of concern to plant breeders and researchers [14]. Germplasm characterization is a crucial point of departure for breeding programs that assists breeders in the identification of the appropriate parental material [15]. Additionally, characterization information is crucial for research management, aiding in the verification of accurate accession labeling during harvesting, monitoring potential source contamination, and defining proper handling procedures for future use. The insufficient of research information on these common bean genotypes limits the variety that is used in Tanzania, specifically in the southern highlands zone. However, a significant number of common bean cultivars are preserved in Tanzania's agricultural research stations [15], [16].

3. RESEARCH OBJECTIVE

To assess phenotypic characteristics of exotic and widely cultivated common bean genotypes in Southern Highlands of Tanzania.

4. RESEARCH METHODOLOY

4.1. The Study Areas

This study was carried out in Tanzania's southern highlands specifically in Mbeya and Songwe regions. Mbeya is at a latitude of 8.28661120 and a longitude of 32.81325370, with GPS coordinates of -8° 17' 11.8" N and 32° 48' 47.713" E, and an elevation of 1,700 meters above mean sea level. Songwe has a latitude of -8.27261200 and longitude of 31.71131740, with GPS coordinates of -8° 16' 21.403" N and 31° 42' 40.743" E, an altitude of approximately 1,469 meters above sea level [31].

4.2 Material and Methods

Twelve common bean genotypes were utilized in these experiments, six (6) were popular and widely cultivated varieties of southern highland of Tanzania and other six (6) were imported from CIAT Colombia. The experiments were conducted in six location of southern highlands in regions of Mbeya and Songwe. These two regions are approximately 2000m altitude above sea level. Experiments were conducted between January 2025 to May 2025. Experimental material used during the experiment are shown in Table 1.

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Table 1: Description of 12 genotypes of exotic (CIAT-Colombia) and popular varieties of southern highlands of Tanzania used during the study

Genotypes Names	Source	Seed colors	Seed size	Growth Habit
Selian 13	Tanzania variety	Yellow	small	Bush
Calima Uyole	Tanzania variety	Red mottled	Large seeded	Bush
Njano Uyole	Tanzania variety	Yellow	small	Bush
Uyole 16	Tanzania variety	Yellow	small	Bush
Kablanket	Tanzania variety	Cream	Large seeded	Bush
Lyamungo 90	Tanzania variety	Red mottled	Large seeded	Bush
22ACC02333	CIAT-COLOMBIA	Red mottled	Large seeded	Bush
22ACC02881	CIAT-COLOMBIA	Red	Large seeded	Bush
22ACC03221	CIAT-COLOMBIA	Large red	Large seeded	Bush
22ACC02433	CIAT-COLOMBIA	Yellow	small	Bush
22ACC02553	CIAT-COLOMBIA	Yellow	small	Bush
22ACC02101	CIAT-COLOMBIA	Yellow	Large seeded	Bush

4.3 Experimental Design

A Randomized Complete Block Design (RCBD) was implemented in six locations across the two regions of Mbeya and Songwe to guarantee statistical reliability. The seeds were planted in four rows in total, with a 50 cm spacing between each row and a 10 cm spacing between plants. However, all of the trial sites were weeded, fertilized, and pest management practices were monitored to guarantee improved performance.

4.4 Data Collection process

Data on phenotypic characterization were collected for five randomly selected plants at every location. Assessment included a variety of descriptors like stem anthocyanin color, leaf size, habit of growth, type of twining, intensity of leaf color, and leaflet shape, among others, as well as some floral traits. Pod traits like pod curvature, seed shape, suture-associated shape, flower color, seed testa color and general seed shape. This structured method provided a comprehensive characterization of common bean germplasm, both the imported ones from CIAT Colombia and the indigenous popular cultivars within the southern highlands of Tanzania.

5. RESULTS AND DISCUSSION

This research facilitated a rigorous evaluation of 12 phenotypic traits to provide the foundation for the choice of genotypes with superior agronomic worth for commercial cultivation, breeding schemes, and market suitability. Examination proved that a lot of variation existed among traits, highlighting their potential for breeding towards improving vigor, yield potential, and adaptability (Table 2).

Table 2: The results of phenotypic characteristics of exotic genotypes and popular varieties of southern highland of Tanzania on eleven (11) phenotypic traits

Name of Varieties	Source	SAC	PG T	PH	LI	LS	FC SP	STC	SH	SS	PTH	LS
Selian 13	Tanzania variety	Abse nt	Ere ct	Determi nate	Lig ht	Ov ate	Whi te	Bro wn	Kidn ey	Small	Non vinyl	Medi um
Calima Uyole	Tanzania variety	Pres ent	Ere ct	Determi nate	Lig ht	Ov ate	Whi te	Red	Kidn ey	Large	Non vinyl	Medi um
Njano Uyole	Tanzania variety	Pres ent	Ere ct	Determi nate	Lig ht	Ov ate	Pin k	Whit e	Ellipt ic	Medi um	Non vinyl	Medi um
Uyole 16	Tanzania variety	Pres ent	Ere ct	Determi nate	Lig ht	Ov ate	Pin k	Whit e	Kidn ey	Medi um	Non vinyl	Medi um

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Kablanket	Tanzania variety	Present	Erect	Determinate	Green	Ovate	White	White	Circular	Medium	Non vinyl	Medium
Lyamungo 90	Tanzania variety	Absent	Erect	Determinate	Light	ovate	pink	Yellow	Circular	Medium	No vinyl	Medium
22ACC02333	Exotic variety	Present	Erect	Determinate	Light	Ovate	White	Red	Kidney	Large	Non vinyl	Medium
22ACC02881	Exotic variety	Present	Erect	Determinate	Green	Ovate	White	White	Circular	Medium	Non vinyl	Medium
22ACC03221	Exotic variety	Absent	Erect	Determinate	Light	ovate	pink	Yellow	Circular	Medium	No vinyl	Medium
22ACC02433	Exotic variety	Absent	Erect	Determinate	Light	Ovate	White	Brown	Kidney	Small	Non vinyl	Medium
22ACC02553	Exotic variety	Present	Erect	Determinate	Light	Ovate	Pink	White	Elliptic	Medium	Non vinyl	Medium
22ACC02101	Exotic variety	Present	Erect	Determinate	Light	Ovate	Pink	White	Elliptic	Medium	Non vinyl	Medium

Note: SAC; Stem Anthocyanin Coloration (absent, present), **PGT;** Plant growth type (erect, semi-erect, spreading), **PH;** Plant habit (Determinate, indeterminate), **LI;** Leaf Intensity (light, dark green), **LS;** Leaf shape (cordate, ovate, hastate,) **FCSP;** Flower color of standard petal (white, yellow, pink, violet), **STC** ; Seed testa color (white, red, dark red, brown, light red, black, yellow), **SH;** Seed shape (kidney, circular, elliptic), **PTH;** Plant twining habit (vinyl, non-vinyl), **LS;** Leaf size (Large, medium, small) and **SS;** Seed size (Large, medium, small).

5.1 DISCUSSION

The evaluation of twelve common bean genotypes on phenotypic characterization shown high variation which offer excellent chances for research purpose of improving common bean crops, expanding genetic resources, as well as increasing marketability. The favorable characteristics, including the deep pigmentation of leaves and erect growth habits, were significant in improving productivity and adaptability across various ecological circumstances [17]. The phenotypic traits under evaluation are explained in detail.

5.2 Plant Growth Type

An erect growth habit was displayed by most of the germplasm lines, which indicate the suitability of genotypes for manual harvesting and great land cultivation practices. The frequency of this growth type is a reflection of its ability to enhance yield and adaptability under diverse environmental conditions. In the same manner, this erect growth trait provides potential options for research projects with objectives of enhancing harvesting efficiency, resistant varieties as well as environmental stress resistance [18]. Upright growth habits also exhibit excellent lodging resistance and are therefore amenable to high-density production; spreading types may have benefits for smallholder, low-input cropping system [19].

5.3 Plant Twining Habit

Great number of genotypes shown a non-viny growth habit, making them stable for row cropping and mechanized farming systems. Their large canopy allows for better air movement, thus lowering the incidence of diseases such as anthracnose and leaf spots [20]. Such types of growth are highly compatible with close cropping systems with small spacing between plants, allowing for efficient weed control and nutrient use, as well as further reducing disease incidence [21]. Also, research on common bean genotypes (*Phaseolus vulgaris L.*) by Uebersax et al., [22] shown extensive variation in plant structure, which has been emphasized to be important for breeding programs for enhancing growth traits for various cropping systems. Non-viny growth types, through their erect and compact habit, possess special utility for practices such as intensive agriculture, high-density planting, and mechanical harvesting [23]. This growth pattern variation reported here is a source of useful genetic material for research projects with objectives at enhancing plant architecture for sustainable agriculture.

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5.4 Plant Habit

The most frequent manifestation of determinate growth habits signifies enhancement in vegetative and reproductive stages, which may result in increased yields under optimum environmental conditions and thus render them of particular importance to farming producers. Furthermore, the determinate growth forms, as present in the lines tested, provide advantages such as synchronized flowering and harvest, especially in regions with short growing seasons where spacing and support systems are of great importance [24]. These results highlight the difference in concentrating on identifying the types of research needed to achieve the goals of productivity in widely phenotypic traits in different common bean varieties.

5.5 Leaf Intensity

The comparatively even spread of light and dense leaves brings out significant variations in leaf intensity that may influence the photosynthetic efficiency and general productivity of the crop. Leaves that are dark green tend to coincide with high chlorophyll concentration, which has the potential to increase photosynthesis and plant vigor [25]. Chlorophyll in combination with other pigments such as carotenoids is largely responsible for leaf coloration and thus influences light absorption, photosynthetic functions, and market acceptability [26]. Besides, diversity in leaf colors plays an important part in selection, especially after crossing various parents, on other side uniqueness of lead intensity characters such as foliar are crucial in determining phenotypic diversity.

5.6 Leaf Shape

Most germplasm lines possess ovate leaflet shapes, which are related to better light interception and possibly greater photosynthetic efficiency. A study on *Phaseolus vulgaris* by Sofi et al., [28] indicates that changes in leaf area development and canopy structure are very important to achieve maximum light capture. This traits are important for breeding programs which its objective is to enhance light interception and maximize yield potential under various agro-ecological conditions.

5.7 Leaflet Size

The frequency of medium-sized leaflets reflects their possible advantages in optimizing photosynthetic surfaces, promotion of growth, and productivity improvement. The leaflets provide greater light capture and therefore improve photosynthesis and plant growth [29]. Park et al., [30] study on *Phaseolus vulgaris* demonstrated leaves through efficient sunshine absorption initiate speedy plant development and thesis of foods in plants that all initiate better yield plant performance.

5.8 Stem Anthocyanin Coloration

Stem Anthocyanin pigments has broadly occurred in most genotypes which indicates a high antioxidant activity, making the genotypes more resistant to environmental stresses like ultraviolet radiation, pest attacks, and natural occurrence deficient like nutrients contents and drought stress [31]. Therefore, an anthocyanin-free germplasm line may exhibit decreased tolerance to such stress conditions, whereas an anthocyanin-rich line may exhibit enhanced stress tolerance as well as resistance to pests and hence good potential for breeding plans to enhance the resistance of plants [32].

5.9 Flower color of standard petal

The prevalence of white and pink flower colors indicate the plants ability to attract certain pollinators, promoting cross-pollination and facilitating genetic diversity. This variation in flower characteristics agrees with [33] experiments on *Phaseolus vulgaris* L that have described substantial differences in phenotypes among genotypes from various sites. Research conducted in the southern highlands of Tanzania by Faria et al., [34] has pointed towards the wide genetic variation that is present in genotypes of the common bean, more specifically with regards to flower traits. This variation give great opportunities for research projects with objectives at enhancing pollination efficiency, aesthetic value, and general farm yield.

5.10 Seed Coat Pigmentation

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The pigmentation in the germplasm lines suggests a potential association with anthocyanin content, which is associated with various advantages including pest resistance, protection against ultraviolet radiation, and increased visual attractiveness [35]. Testa coloration of seeds is a very important feature in plant development that affects seed viability, germination percentage, and general visual attractiveness [36], [37]. In this research, testa pigmentation—ranging from white, yellow, red, to brown was controlled by certain pigments, differing according to plant variety and species. These results indicate the twofold significance of pigmentation as an adaptive characteristic for environmental tolerance and as a visible attribute influencing market preferences

5.11 Seed Morphology

The morphological diversity among seeds of the germplasm is manifested by the common occurrence of circular and elliptic shape, and kidney-shaped and circular-to-elliptic shapes. These morphological differences are important from a cooking and processing perspective since seed shape affects handling, preparation, and various culinary applications [38]. Studies by Gonzalez et al., [39] on several common bean genotypes had also highlighted such variability, with most of the seeds showing elliptic or kidney shapes and lacking perfectly round shapes. Supporting these observations, a study by Beebe et al., [40] comprising 42 common bean genotypes from Northern Tanzania has revealed extensive phenotypic variation, hence highlighting the richness of the genes inherent in the germplasm. These morphological variations are helpful in reference variety identification in breeding programs and enhancing genetic selection activities.

5.12 Implication to Breeding Programs and Future Research

The thorough phenotypic evaluation of the widely cultivated genotypes and exotic genotypes imported from CIAT-Colombia in the present study identifies priority traits with high potential for use in research projects in common bean characterization, adaptation, as well as market acceptability. Characteristics such as pale green color of leaves, erect habit, thickness of pod suture, color of seed testa form a basis for inheritance in terms of research and in terms of plants adaptation for climatic condition and productivity to wide ecological conditions of Tanzania Sothern highlands. A lot more research effort must be channeled in assessing other related characters in common bean development and performance such as common bean diseases, tolerance to adverse weather condition, and farmer's nutritional acceptability utilizing multi-location trials in large environments in the region. In addition, incorporation of advanced molecular evaluation level and molecular genomics should be inclusive in meaningful terms for revealing the alleles associated with the traits of interest.

6. CONCLUSION

Assessing the phenotypic traits of common bean genotypes establishes a solid basis for breeding initiatives focused on enlightening harvest steadiness, adaptability, and flea market worth in large-scale production agro-ecology, specifically for Mbeya and Songwe districts of the southern highlands of Tanzania. The large variation for the phenotypic characters includes the characters in the growth, leaf shape and size, flowering, beans pod morphology as well as seed testa color offers promising phenotypic characteristics for scientific research. Breeding for such characters of upright plant growth habit, pod structures and seed testa can enhance stress tolerance, facilitate mechanical harvest, and increase market acceptability.

Policy makers have an important function to perform in backing these initiatives by scaling up access to these seeds research institution, launching training programs for farmers, and coming up with farm policies to improve crop productivity and resilience. Furthermore, breeding strategies must emphasize the creation of disease- and drought-resistant varieties, exploiting the natural genetic diversity to adjust to climatic shifts and solidify food security.

This is a convenient overall description for breeding programs with which commercially useful cultivars can be produced with particular regional conditions in mind. The identified genotypes characterized by their typical phenotypic traits form an excellent foundation for the resolution of climate and other issues, and for the establishment of sustainable crop production. These results reflect on the significant role of common bean genotypes in improvement research trials which can to lead sustainable common bean production and sustainable food availability to the community in Tanzania's southern highlands, such as Mbeya and Songwe, and beyond.

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