RESEARCH PAPER

Evaluation of high-yielding groundnut genotypes in preliminary trials at NARC, Islamabad, Pakistan

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Key Message: This study evaluated fifteen groundnut genotypes and revealed that genotype GP-1265 demonstrated the highest yield (2293 kg ha^{-1}) and outperforming the popular check variety BARD-479 by 36 percent. This emphasizes the importance of identifying and adopting high-yielding genotypes to enhance groundnut production in the region.

Abstract

Groundnut (*Arachis hypogaea*) is a very vital legume crop which is usually grown in rain fed areas of Pakistan. Productivity potential of groundnut genotypes in our cropping systems is very important for the development of an agricultural system that is sustainable, environmentally passionate and has a capacity to produce enough production to fulfill the demand of the people for groundnut. To increase production it is the need of the hour to evaluate and identify the best suiting genotypes of groundnut. Fifteen genotypes of groundnut were planted for the purpose of evaluation. All the agronomic or cultural practice was kept same for the genotypes under evaluation. The study was conducted at Oil Seed Program, National Agricultural Research Centre (NARC), Park Road, Chak Shahzad, Islamabad, Pakistan. The experiment used a randomized complete block design (RCBD) with 3 replications. The study was aimed to assess and identify the genotypes/cultivars, which produce high yield for general adoption in the country. The results of the study revealed that genotype GP-1265 was the highest yielding genotype which produced 2293 kg ha^{-1} dry pod yield, while the second one genotype was PG-1267 which produced 2201.9 kg ha^{-1} dry pod yield. The lowest yield was obtained from the cultivar BARD-479 i.e., 1456.6 kg ha^{-1}. Among the fifteen entries evaluated in these preliminary yield trials, PG-1265 showed the maximum mean dry pods yield of 2293.3 kg ha^{-1} as compared to check variety BARD-479 with mean dry pods yield of 1132 kg ha^{-1}. This showed that per hectare yield of PG-1265 was 36 percent more as compared to check variety BARD-479, which is the most common and popular variety of Pothohar region of Pakistan. However, dry pod yield is highly correlated with pod yield per plant, 100 seed weight and seed yield.

Keywords: Arachis hypogaea, Evaluation, General adoption, Genotype identification, Productivity potential

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Introduction

Groundnut (*Arachis hypogaea*) is a monoecious annual legume crop mainly grown for food, oilseed and animal feed. It is an allotetraploid crop having choromosome number x = 10 with self-pollination mode. It belongs to family Leguminose and sub-family paillionoidae. Its seed contains about 48 % oil content, 25 % proteins and about 18 % carbohydrates. Groundnut is a great reservoir of vitamins B- complex, minerals, antioxidants, flavanoids, isoflavones and biologically active polyphenols (Desai et al., 1999; Pande et al., 2003; Roomi et al., 2013). It is cultivated in more than hundred countries worldwide with an annual production of 45.95 million tons of shelled grains approximately and mainly used for oil (Upadhyaya et al., 2012).

Groundnut is a prominent food source, which is widely consumed worldwide. It is grown on sandy soil in tropical and subtropical regions of the world (Janila et al., 2013; Oteng-Frimpong et al., 2017). The production methods vary from highly advanced commercial practices in the Western countries to more conventional farming approaches in third world countries (Pimratch et al., 2008). In Pakistan, groundnut is mainly cultivated in rain-fed areas of Punjab like Chakwal, Jehlum, Rawalpindi and some areas of Attock. The weather conditions in these areas are unpredictable with uncertain rainfall and shortage of water (Khan et al., 2001; Ahmad et al., 2007; Abid et al., 2009).

Groundnuts are consumed as peanut butter, crushed and used to prepare groundnut oil. It is also used as a sugary snack when roasted, salted, or in sweets (Naeem-ud-Din et al., 2012). In various parts of the world, they are boiled either with or without shell. Depending upon production area and production system, yields of groundnut range from 400 kilograms to several tonnes per hectare. It is given a great priority to groundnut in the whole world due to its valuable characteristics. Groundnut has a high capacity to generate income for the growers and it becomes healthier food for the consumers because of its excellent nutritious values. The crop gains high scores for nutrition, quality, integrity, acceptability, affordability along with investment interest (Anim-Somuah et al., 2013). Groundnut is cultivated under irrigated or rain-fed conditions during summer in rainfed regions. The poor farmers especially in South Africa grow groundnuts only for subsistence (Ajeigbe et al., 2015). Soleri et al. (2000) stated that there is a specific criterion for selection of new varieties. It depends on the significance of the cultivated crop in the farming system and its usage. Groundnut growers prefer mainly those varieties of groundnut which are high yielding, large seeded and have resistance to diseases. These are the characteristics which have prime importance for breeders while developing a new variety. If a variety developed by considering these characteristics, it will save resources. Cultivation and adoption of highly productive groundnut variety is the need of the hour.

In Pakistan, average yield of groundnut with shells is very low because of unimproved varieties, defective rainfall, insect pests and diseases and lack of interest of government (Qasim et al., 2016). Because of unavailability of improved varieties and seeds, mostly farmers recycle the seeds which also create hurdles in obtaining high yield of groundnut (Doss et al., 2003). Diseases like early leaf spot are the major diseases of groundnut which when occurs in epidemic form may results in 100 % of yield losses. However, rust and late leaf spot of groundnut are also economically important in some countries and usually occur together in area of low altitude (Bock, 1987). This has great concern for breeders, farmers and also for policy makers for betterment of groundnut varieties and their introduction and multiplication in the country (Kaizzi et al., 2006). A cultivar or genotype is to be considered as more stable or adaptable as it has high ability to produce grain with minimum fluctuations in yielding capability over changing climatic conditions (Punto et al., 1982). In other regions, the crop can support farming methods that are more viable and profitable. It is an excellent rotation crop which can replace monoculture maize and enrich the soil with nitrogen (Mokgehle et al., 2014). Compared to many other crops, groundnut cultivation requires greater management skills thereby successful farmers are those who follow the recommended management practices (Hyndavi, 2015). The purpose of the study was to evaluate performance of the fifteen different genotypes of groundnut and their yield related parameters.

Materials and Methods

Study locations

The present study was conducted during the year 2017 at the Oil Seed Program, National Agricultural Research Centre (NARC), Park Road, Chak Shahzad, Islamabad, Pakistan.

Plant material

Fifteen genotypes of groundnut were obtain from various research institutes and used for evaluation in the study. These experimental materials (genotypes) comprised of conventional groundnut cultivars and various elite genotypes viz. BARD-479, PG-1254, PG-1255, PG-1256, PG-1257, PG-1258, PG-1259, PG-1260, PG-1261, PG-1262, PG-1263, PG-1264, PG-1265, PG-1266 and PG-1267 cultivated in the highlands of Pakistan.

Experimental trial

The present research work was carried out on groundnut during the kharif season of year 2017 using Randomized Complete Block Design (RCBD). Each trial was replicated three times. All the agronomic practices were kept same for the genotypes under cultivation during period of study. Each study unit comprises of three rows of 4 m length and each plot is spaced 0.5 m apart. The plant to plant distance was 15cm and row to row distance of 50cm was maintained by planting two seeds of each genotype. The process of thinning was done after 20 days of sowing and one plant per spot is maintained. Harvesting was done at physiological maturity of 10 randomly selected plants. The number of pods per plant and number of grains per pod were counted after drying of plants as well as pods. Four rows of each plot were harvested and seed yield was estimated per plot and then the yield was converted into kg ha^{-1}.

Data collection and analysis

The study collected and recorded data on the following for each of the 15 studied groundnut genotypes: plant height (cm), number of branches per plant, leaf width (cm), leaf length (cm) and plant canopy (cm). For recording the data about pod yield (kg ha^{-1}), methods described by Khan et al. (2009) was used. The plants were harvested from each plot then pods were dehydrated under sun and weighed for pod yield per subplot. The yield was changed into kg ha^{-1} by following formula given by Khan et al. (2009):

Pod yield (kg ha^{-1}) = [(Pod yield $plot^{-1}$ (kg) / Plot size (m^2)] × 10,000 m^2

Results of the study were analyzed according to the Steel et al. (1997); Singh & Chaudhry (2004). Two way of analysis of variance was calculated using the statistical software STATISTICS 8.1.

Results and Discussion

Plant height

Data of plant height was measured when all the genotypes have reached at 90 % maturity. Due to different genetic backgrounds, all the genotypes under study differ from each other and showed significant differences in case of plant height. Fikreselassie (2012) conducted a study and found that significant variations are present for the trait and also stated that plant height is one of the traits which have positive relation and greater influence. Results of the study showed that the maximum height plant height was observed in genotype BARD-479 and PG-1256 i.e. 77.667 cm and 71 cm, respectively. Similarly medium height examined in plants of genotype PG-1255 and PG-1254 i.e. 56 cm and 52 cm, respectively (Table 1). The lowest plant height was examined in genotype PG-1265, PG-1262 and PG-1260 i.e., 42.33 cm, 41.00 cm and 38 cm, respectively. Plant height might be a significant trait for recommendation of a variety because it has a positive relation with yield. Plant with more height, produce fewer yield. The results are in line with the findings of John et al. (2015). They reported that plant yield is positively correlated with the height of plant.

Table 1 Plant height (cm) and least significant difference (LSD) test of all-pair-wise comparisons of plant height of genotypes

S. No.	Genotypes	Plant height (cm)	S. No.	Genotypes	Plant height (cm)
1	BARD-479	77.667^{a}	9	PG-1261	47.333^{cde}
2	PG-1254	52.667^{b-e}	10	PG-1262	41.000^{e}
3	PG-1255	56.000^{b-e}	11	PG-1263	68.333^{ab}
4	PG-1256	71.000^{ab}	12	PG-1264	65.667^{abc}
5	PG-1257	44.667^{de}	13	PG-1265	42.333^{e}
6	PG-1258	66.333^{ab}	14	PG-1266	61.333^{a-d}
7	PG-1259	68.667^{ab}	15	PG-1267	65.667^{abc}
8	PG-1260	38.000^{e}			

Observations per mean = 3; Standard error of a mean = 6.3938; Grand mean = 1752.2; CV = 57.778; Alpha = 0.05; Standard error for comparison = 9.0422; Critical T value = 2.048; Critical value for comparison = 18.522; Error term used: REP*Gen 28 D.F.; There are 5 groups (A, B, etc.) in which the means are not significantly different from one another.

Number of branches per plant

Number of branches per plant is also a key factor which contributes in yield parameters of plant. The data in Table 2 showed that there is huge difference in number of branches per plant among all the genotypes. The maximum number of branches was recorded in genotype PG-1265 followed by PG-1258, PG-1260, PG-1262 and PG-1266. Almost remaining genotypes followed the same pattern and there is no significant differences found in number of branches. However, the fewest number of branches were found in genotype PG-1255 and PG-1256. Although, there is no significant difference was found among the genotypes evaluated during the course of study. Plant with more number of branches is able to produce more biomass and ultimately more yield. The results of the study are at par with the findings of El-Naim et al. (2011). They concluded that more branching in groundnut may have very positive impact on yield of groundnut.

Table 2 Number of branches and least significant difference (LSD) test of all-pair-wise comparisons of number of branches of genotypes

S. No.	Genotypes	Number of branches	S. No.	Genotypes	Number of branches
1	BARD-479	7.000^{c}	9	PG-1261	10.667^{ab}
2	PG-1254	10.667^{ab}	10	PG-1262	11.000^{ab}
3	PG-1255	6.333^{c}	11	PG-1263	8.333^{abc}
4	PG-1256	6.33^{c}	12	PG-1264	10.667^{ab}
5	PG-1257	8.000^{bc}	13	PG-1265	11.333^{a}
6	PG-1258	11.000^{ab}	14	PG-1266	11.000^{ab}
7	PG-1259	8.333^{abc}	15	PG-1267	9.333^{abc}
8	PG-1260	11.000^{ab}			

Observations per mean = 3; Standard error of a mean = 1.1276; Grand mean = 9.4; CV = 20.78; Alpha = 0.05; Standard error for comparison = 1.5946; Critical T value = 2.048; Critical value for comparison = 3.2665; Error term used: REP*Gen 28 D.F.; There are 3 groups (A, B, etc.) in which the means are not significantly different from one another.

Leaf width (cm)

The results in Table 3 showed that the values of leaf width also vary among all the genotypes under consideration. The highest value of leaf width was observed by the genotype PG-1256 and PG-1262 having leaf width of 2.7 cm. Similarly, value of leaf width in genotype PG-1255 is 2.5 cm. On the other hand lowest value of leaf width was observed in genotype PG-1264. Genotypes PG-1256 and PG-1263 showed a value of 2.66 cm and in genotype PG-1260 value of 2.66 cm was obtained. However, there are no significant differences observed in genotypes evaluated in the study as all these showed an almost similar trend in case of leaf width. Leaf width is a crucial morphological trait that can influence plant growth, development, and overall productivity. One of our findings shows the considerable variability in leaf width among these genotypes. The genotype PG-1256 and PG-1262 exhibited the highest leaf width, both measuring 2.7 cm. This suggests that these genotypes may possess characteristics or genetic traits that contribute to broader leaves. On the other hand, genotype PG-1264 displayed the lowest leaf width, indicating a potential genetic or physiological difference that results in narrower leaves. The intermediate values observed in genotypes PG-1255, PG-1263, and PG-1260 (2.5 cm, 2.66 cm, and 2.66 cm, respectively) suggest a moderate range of leaf width in these genotypes. While there are slight variations, the overall trend in leaf width among these genotypes seems to be relatively consistent, as indicated by the lack of significant differences. Hence, leaf width variations among different genotypes provide a foundation for understanding the genetic diversity within the studied population.

Leaf length (cm)

Data of trials showed that there is also a variation observed in leaf length of different genotypes under observation. Maximum length of leaf was recorded in genotype PG-1254. Genotypes PG-1255, PG-1259, BARD-479, PG-1258, PG-1263, PG-1264, PG-1261 showed values of leaf length 6.66cm, 6.266 cm, 5.966 cm, 5.90 cm, 5.5 cm, 5.3 cm, and 5.233 cm, respectively. Remaining genotypes showed a similar pattern in length of leaf. On the other hand, genotype PG-1265 exhibited the lowest leaf length.

Leaf length is an important factor influencing the overall plant structure and can indicate the genetic diversity in a population (Shi et al., 2019). Genotype PG-1254 showed the maximum leaf length, signifying that this genotype possesses genetic traits or physiological characteristics favorable for longer leaf development. The important factors should be studied for longer leaf length in PG-1254 which might be valuable for improving specific traits of plants related to leaf morphology in various breeding programs. The other genotypes exhibited consistent pattern in leaf length suggesting a level of uniformity in genetic traits among them. Due to shared traits in these genotypes, genetic markers linked to leaf length could be identified for developing plants with desired leaf characteristics. The variation in leaf length of these genotypes stresses the significance of genetic diversity in plant populations. The varieties can be developed with specific traits such as optimal leaf length which can influence photosynthesis, nutrient absorption, and overall plant performance by utilizing this diversity in crop improvement programs (Richards, 2000).

Table 3 Leaf width (cm) and least significant difference (LSD) test of all-pairwise comparisons of leaf width of genotypes

S. No.	Genotypes	Leaf width (cm)	S. No.	Genotypes	Leaf width (cm)
1	BARD-479	2.133^{cde}	9	PG-1261	2.166^{cd}
2	PG-1254	2.333^{bcd}	10	PG-1262	2.700^{a}
3	PG-1255	2.500^{ab}	11	PG-1263	2.666^{bcd}
4	PG-1256	2.700^{a}	12	PG-1264	1.633^{f}
5	PG-1257	2.300^{bcd}	13	PG-1265	2.200^{bcd}
6	PG-1258	2.266^{bcd}	14	PG-1266	1.83^{ef}
7	PG-1259	2.666^{bcd}	15	PG-1267	2.100^{de}
8	PG-1260	2.433^{abc}			

Observations per mean = 3; Standard error of a mean = 0.1129; Grand mean = 2.3089; CV = 8.47; Alpha = 0.05; Standard error for comparison = 0.1597; Critical T value = 2.048; Critical value for comparison = 0.3272; Error term used: REP*Gen 28 D.F.; There are 6 groups (A, B, etc.) in which the means are not significantly different from one another.

Table 4 Leaf length (cm) and least significant difference (LSD) test of all-pair-wise comparisons of leaf length of genotypes

S. No.	Genotypes	Leaf length (cm)	S. No.	Genotypes	Leaf length (cm)
1	BARD-479	5.966^{bcd}	9	PG-1261	5.233^{e-h}
2	PG-1254	7.000^{a}	10	PG-1262	4.766^{ghi}
3	PG-1255	6.666^{ab}	11	PG-1263	5.500^{def}
4	PG-1256	5.900^{cde}	12	PG-1264	5.300^{d-g}
5	PG-1257	5.466^{d-g}	13	PG-1265	4.266^{hi}
6	PG-1258	5.900^{cde}	14	PG-1266	5.166^{fgh}
7	PG-1259	6.266^{bc}	15	PG-1267	4.866^{f-i}
8	PG-1260	4.566^{hi}			

Observations per mean = 3; Standard error of a mean = 0.2448; Grand mean = 5.5222; CV = 7.68; Alpha = 0.05; Standard error for comparison = 0.3462; Critical T value = 2.048; Critical value for comparison = 0.7092; Error term used: REP*Gen 28 D.F.; There are 9 groups (A, B, etc.) in which the means are not significantly different from one another.

Plant canopy (cm)

The data in Table 5 showed that all the fifteen genotypes are differing from each other on the basis of plant canopy. Maximum plant canopy was found in genotype PG-1256 and the lowest plant canopy was noticed in genotype GP-1262. The maximum plant canopy was recorded in genotype PG-1256, and the lowest plant canopy was found in genotype PG-1262 that indicates the existence of a wide spectrum of plant canopy characteristics among the genotypes. This range suggests that genetic factors play a significant role in determining the lateral spread of the plants. Understanding such genetic diversity is vital for plant breeding programs where specific plant traits such as canopy, may be targeted for modification to meet specific agricultural or commercial objectives. The fact that all fifteen genotypes exhibit differences in plant canopy emphasizes the complexity of the genetic factors influencing this trait. This variation could arise from a combination of factors including the presence of different alleles, gene expressions, or environmental interactions (Richards, 2000).

Table 5 Plant canopy (cm) and least significant difference (LSD) test of all pair-wise comparisons of plant canopy of genotypes

S. No.	Genotypes	Plant canopy (cm)	S. No.	Genotypes	Plant canopy (cm)
1	BARD-479	148.00^{ab}	9	PG-1261	86.00^{hi}
2	PG-1254	133.00^{bc}	10	PG-1262	65.00^{kl}
3	PG-1255	84.33^{hi}	11	PG-1263	111.00^{def}
4	PG-1256	155.67^{a}	12	PG-1264	128.67^{cd}
5	PG-1257	120.33^{cde}	13	PG-1265	108.33^{efg}
6	PG-1258	91.67^{ghi}	14	PG-1266	96.67^{fgh}
7	PG-1259	99.33^{fgh}	15	PG-1267	$105.67^{e\text{-}w}$
8	PG-1260	77.00^{ij}			

Observations per mean = 3; Standard error of a mean = 6.4664; Grand mean = 107.38; CV = 10.43; Alpha = 0.05; Standard error for comparison = 9.1448; Critical T value = 2.048; Critical value for comparison = 18.732; Error term used: REP*Gen 28 D.F.; There are 10 groups (A, B, etc.) in which the means are not significantly different from one another.

Dry pod yield

Dry pod yields significantly varied among the genotypes under consideration in these trials. In the initial yield trials of fifteen entries, PG-1265 demonstrated the highest average dry pod yield at 2293.3 kg ha^{-1}, surpassing the check variety BARD-479 which had a mean dry pod yield of 1132 kg ha^{-1}. This showed that per hectare yield of PG-1265 is high as 36 percent more as compared to check variety BARD-479 which is the most common and popular variety in Pothohar region of Pakistan. The results of the preliminary yield trials showed that the genotypes producing more number of mature pods are high yielding varieties were PG-1296, PG-1267 and PG-1266 with yield 2296.3 kg ha^{-1}, 2201.9 kg ha^{-1} and 2104.7kg ha^{-1}, respectively. The Genotype PG-1255 and PG-1259 showed the dry pods yield of 1865.9 kg ha^{-1} and 1712.6 kg ha^{-1}, respectively (Table 1). Genotypes which produced the minimum yield were BARD-479, PG-1263 and PG-1264 with yield values of 1132 kg ha^{-1}, 1174 kg ha^{-1}, 1456.6 kg ha^{-1}, respectively. A similar study was conducted by Nawaz et al., (2013) and found that similar results were obtained in the preliminary yield trials. They concluded that the dry pod yield is highly correlated with number of pods per plant. Increase in seed size and pods per plant are important parameters for improvement in groundnut varieties. In a previous research study, large seeded mutants were detected in a groundnut cv. Georgia Browne (Branch, 2002). Many researchers reported large seed size as an important indicator of seed yield in chickpea (Waldia et al., 1996; Mehla et al., 2000).

Table 6 Values of dry pod yield (DPY) and least significant difference (LSD) test of all-pairwise comparisons of DPY for genotypes

S. No.	Genotypes	Mean	S. No.	Genotypes	Mean
1	BARD-479	1456.6^{hi}	9	PG-1261	$2039.2^{a\text{-}d}$
2	PG-1254	$1774.3^{d\text{-}g}$	10	PG-1262	$1933.1^{b\text{-}e}$
3	PG-1255	$1865.9^{c\text{-}f}$	11	PG-1263	1174.5^{ij}
4	PG-1256	1599.4^{fgh}	12	PG-1264	1132.9^{j}
5	PG-1257	1502.2^{gh}	13	PG-1265	2296.3^{a}
6	PG-1258	$1978.7^{b\text{-}e}$	14	PG-1266	2104.7^{abc}
7	PG-1259	$1712.6^{e\text{-}h}$	15	PG-1267	2201.9^{ab}
8	PG-1260	1510.5^{gh}			

Observations per mean = 3; Standard error of a mean = 102.44; Grand mean = 1752.2; CV = 10.13; Least Significant Difference (LSD) test of all-pairwise comparisons was applied for DPY of genotypes; Alpha = 0.05; Standard error for comparison = 144.87; Critical T value = 2.048; Critical value for comparison = 296.75; Error term used: REP*Gen; D.F. = 28; There are 10 groups (A, B, etc.) in which the means are not significantly different from one another.

Conclusion

The results of the study showed that the genotype PG-1265 is one of the best genotypes among the fifteen genotypes under consideration. The mean maximum value of dry pod yield produced by the genotype GP-1265 is 2296.3 kg ha^{-1} which is 36 percent more as compared to the check variety BARD-479 with dry pod yield of 1456.6 kg ha^{-1} and it is recommended for cultivation in the area. However, further research may be required to check the response of PG-1265 in other areas of the groundnut cultivation.

References

Abid, M., Khattak, G. S. S., Iqbal, S., & Hassan, M. F. (2009). High yielding groundnut (Arachis hypogea L.) variety "Golden." *Pakistan Journal of Botany, 41*(5), 2217-2222.

Ahmad, N., Rahim, M., & Khan, U. (2007). Evaluation of different varieties, seed rates and row spacing of groundnut, planted under agro-ecological conditions of Malakand Division. *Journal of Agronomy, 6*(2), 385-387.

Ajeigbe, H. A., Waliyar, F., Echekwu, C. A., Ayuba, K., Motagi, B. N., Eniayeju, D., & Inuwa, A. (2015). A farmer's guide to groundnut production in Nigeria. Patancheru 502-324, Telangana, India: International Crops Research Institute for the Semi-Arid Tropics.

Anim-Somuah, H., Henson, S., Humphrey, J., & Robinson, E. (2013). Strengthening agri-food value chains for nutrition: mapping value chains for nutrient-dense foods in Ghana (No. Evidence Report; 2). Institute of Development Studies (IDS).

Bock, K. R. (1987). Rosette and early leaf spot diseases: a review of research progress, 1984/85. Pages 5-14 in Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe (Bock, K.R., Cole, D.L., Wightman, J.A., and Nigam, S.N., eds.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Branch, W. D. (2002). Variability among advanced gamma-irradiation induced large-seeded mutant breeding lines in the 'Georgia Brownw' peanut cultivar. *Plant Breeding*, *121*, 275.

Desai, B. B., Kotecha, P. M., & Salunkhe, D. K. (1999). Composition and nutritional quality. Introduction science and technology of groundnut: biology, production, processing and utilization. Naya Prokash Publ, New Delhi, India, 185-199. doi:10.3389/fpls.2013.00023.

Doss, C., Mwangi, W., & Verkuijl, H. (2003). Adoption of maize and wheat technologies in Eastern Africa: A synthesis of the findings from 22 case studies. CIMMYT Economics Working Paper 03-06.

El-Naim, A. M., & Eldouma, M. A. (2011). Influence of weeding frequency and plant population on yield and yield components of groundnut (*Arachis hypogaea* L.) in North Kordofan of Sudan. *Bioresearch Bulletin*, *5*(1), 322-328.

Fikreselassie, M. (2012). Variability, heritability and association of some morpho-agronomic traits in field pea (*Pisum sativum* L.) genotypes. *Pakistan Journal of Biological Sciences*, *15*(8), 358.

Hyndavi, Y. (2015). Genetic variability studies in f4 and f5 populations of selected crosses for traits related to water use efficiency, pod yield and its components in ground (*Arachis hypogaea* L.) (Doctoral dissertation, University of Agricultural Sciences, GKVK).

Janila, P., Nigam, S. N., Pandey, M. K., Nagesh, P., & Varshney, R. K. (2013). Groundnut improvement: use of genetic and genomic tools. Frontiers in Plant Science.

John, K., Reddy, P. R., Reddy, P. H., Sudhakar, P., & Reddy, N. P. (2015). Character association and path coefficient analysis for yield, yield attributes and water use efficiency traits in grounndut (*Arachis hypogaea* L.)-A review. *Agricultural Reviews*, *36*(4), 277-286.

Kaizzi, C. K., Ssali, H., & Vlek, P. L. (2006). Differential use and benefits of Velvet bean (Mucuna pruriens var. utilis) and N fertilizers in maize production in contrasting agro-ecological zones of E. Uganda. *Agricultural Systems, 88*(1), 44-60.

Khan, A., Bano, A., Bakht, J., Khan, S. A., Malik, N. J., & Naz, I. (2009). Response of exotic Ground nut Genotypes to environmental diversities at higher altitude of Northern Pakistan. *Sarhad Journal of Agriculture*, *25*(4), 545-550.

Khan, A., Rahim, M., Khan, A., & Khan, M. I. (2001). Yield response of groundnut genotypes under the sub-mountainous conditions of Malakand Division (NWFP), Pakistan. *Pakistan Journal of Biological Sciences, 4*(4), 404-406.

Mehla, I. S., Waldia, R. S., Singh, V. P., Lather, V. S., & Dahiya, S. S. (2000). Association of seed mass groups and seed yield in kabuli chickpea. *International Chickpea Newsletter*, *7*, 7-8.

Mokgehle, S. N., Dakora, F. D., & Mathews, C. (2014). Variation in N2 fixation and N contribution by 25 groundnut (Arachis hypogaea L.) varieties grown in different agro-ecologies, measured using 15N natural abundance. *Agriculture, Ecosystems & Environment*, *195*, 161-172.

Naeem-ud-Din, M. T., Naeem, M. K., Hassan, M. F., Rabbani, G., Mahmood, A., & Iqbal, M. S. (2012). Development of BARI-2011: A high yielding, drought-tolerant variety of groundnut (*Arachis hypogaea* L.) with 3-4 seeded pods. *Journal of Animal and Plant Sciences*, *22*(1), 120-125.

Nawaz, N., Khan, M. A., Amjad, M., Khan, M. A., Ahsan, Z., Asad, S., & Cheema, N. M. (2013). Pothowar: A high yielding medium duration groundnut variety suitable for release and commercial cultivation in Pakistan. *Pakistan Journal of Agricultural Research*, *35*(1), 172-180.

Oteng-Frimpong, R., Konlan, S. P., & Denwar, N. N. (2017). Evaluation of selected groundnut (Arachis hypogaea L.) lines for yield and haulm nutritive quality traits. *International Journal of Agronomy*, *2017*, 1-9. https://doi.org/10.1155/2017/7479309

Pande, S., Bandyopadhyay, R., Blümmel, M., Rao, J. N., Thomas, D., & Navi, S. S. (2003). Disease management factors influencing yield and quality of sorghum and groundnut crop residues. *Field Crops Research*, *84*(1-2), 89-103.

Pimratch, S., Jogloy, S., Vorasoot, N., Toomsan, B., Patanothai, A., & Holbrook, C. C. (2008). Relationship between biomass production and nitrogen fixation under drought-stress conditions in peanut genotypes with different levels of drought resistance. *Journal of Agronomy and Crop Science*, *194*(1), 15-25.

Punto, N. G., & Lantican, R. M. (1982). Genotype × environment interaction for yield in field legumes: II. Mungbean [*Vigna radiata* (L.) Wilczek]. *Philippine Journal of Crop Science*, *7*(3), 137-140.

Qasim, M., Bakhsh, K., Tariq, S. A., Nasir, M., Saeed, R., & Mahmood, M. A. (2016). Factors affecting groundnut yield in Pothwar region of Punjab, Pakistan. *Pakistan Journal of Agricultural Research*, *29*(1), 76-83.

Richards, R. A. (2000). Selectable traits to increase crop photosynthesis and yield of grain crops. *Journal of Experimental Botany*, *51*(suppl_1), 447–458. https://doi.org/10.1093/jexbot/51.suppl_1.447

Roomi, S., Sabiha, B., Zia, M. A., Iqbal, A., Kumar, T., Ahmad, M. Z., Shah, S. H., Rashid, F., Ghafoor, A., Ali, N., & Suleman, M. (2013). Protocol optimization for deoxyribonucleic acid (DNA) extraction from dried, fresh leaves, and seeds of groundnut (*Arachis hypogaea* L.). *African Journal of Biotechnology*, *12*(51), 7070-7073.

Shi, P. J., Liu, M. D., Yu, X. J., Johan, G., & David, A. R. (2019). Proportional relationship between leaf area and the product of leaf length and width of four types of special leaf shapes. *Forests*, *10*(3), 178.

Singh, R. K., & Chaudhary, B. D. (2004). Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, India.

Soleri, D., Smith, S. E., & Cleveland, D. A. (2000). Evaluating the potential for farmer and plant breeder collaboration: a case study of farmer maize selection in Oaxaca, Mexico. *Euphytica*, *116*(1), 41-57.

Steel, R. G. D., Torrie, J. H., & Dickey, D. A. (1997). Principles and Procedures of Statistics, a Biometrical Approach. McGraw Hill Book Co., New York, USA.

Upadhyaya, H. D., Mukri, G., Nadaf, H. L., & Singh, S. (2012). Variability and stability analysis for nutritional traits in the mini core collection of peanut. *Crop Science*, *52*(1), 168-178.

Waldia, R. S., Singh, V. P., Sood, D. R., Sardana, P. K., & Mehla, I. S. (1996). Association and variation among cooking quality traits in kabuli chickpea (*Cicer arietinum* L.). *Journal of Food Science and Technology*, *33*(5), 397-402.