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Multilocational evaluation of some elite taro genotypes and their economic implications as food and income security

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Abstract

Taro production and utilization in Ghana has dwindled due to the outbreak of the taro leaf blight disease. High yielding crop varieties trigger high productivity agro-based economy. Adoption of new cultivar is linked to yield, taste and preference of end-users. The objectives were to assess some taro genotypes for farmer- and consumer-preferred attributes, and economic feasibility. Orthogonal analysis was significant for parameters studied. G x E was significant for only plant height, while genotypic differences were significant for corm yield and corm weight, and corm dry matter content. Genotypes BL/SM 158, BL/SM 115, BL/SM 151, and BL/SM 16 had higher corm yield and higher tolerance to taro leaf blight disease. Benefit-cost ratio was positive. Adoption of these four genotypes as cultivars will revive the taro industry in Ghana because of their higher tolerance to the taro leaf blight disease, higher corm yield, very good cooking qualities and potential higher incomes.

Keywords: Food security, G x E, genotype, income security, multilocational, taro

Introduction

Taro (*Colocasia esculenta* (L.) Schott) is a herbaceous monocotyledonous perennial root crop widely cultivated in tropical and subtropical regions [1]. It originated from South and Southeast Asia and the Pacific Islands [2], and was introduced to the east coast of Africa over 2000 years ago. Taro is an important staple crop for millions of people in developing countries [3]. It is one of the traditional crops with tremendous nutritional and pharmaceutical potential compared to the other root and tuber crops. Different parts of it contains a combination of bioactive compounds including polysaccharides, alkaloids, polyphenols, and saponins which offer anti-carcinogenic, anti-compulsive, anti-hyperglycaemia, anti-hypertensive, and anti-inflammatory as well as hepatoprotective, immunoprotective, and neuroprotective properties. Its small starch granules size, resistant starch, and hypoallergenic properties have the potential to raise its status from underutilized crop resource to an industrial crop status [4]. Taro has until the outbreak of the taro leaf blight disease (TLBD) been utilized as a key staple crop in West Africa, particularly in Ghana [5] and Cameroon [6]. The disease, caused by *Phytophthora colocasiae* is the most destructive biotic constraint causing heavy corm yield losses in many countries [7]. It has been the major constraint to taro production and utilization in Ghana. Its impact can cause farmers to abandon their taro farms and change to other staple crops [8], which is the case in Ghana where most farmers switched to rice and vegetables production. The pathogen can also cause a serious post-harvest deterioration of corms.

Cultural and chemical management techniques of TLBD have largely been ineffective, and breeding for disease resistance has become the most sustainable strategy to manage the disease [9], for higher corm yield and sustainable higher farmer incomes. High yielding cultivars trigger a shift from low productivity agro-based economy to a high productivity agro-industry [10, 11]. Adoption of a new improved crop variety is intricately link to field and yield performance, as well as consumer taste and preference [12]. Some improved cultivars were previously not adopted by farmers due to inadequate attention to end-users' preference in their development [13, 14, 15]. Effective crop breeding should therefore, be hinged on flawless identification of end-user constraints and preferences [16, 17, 18].

Higher corm yields, higher corm dry matter content, plant architecture and tolerances to major diseases and pests are important attributes that influence farmers' acceptability and consumer preference for taro in West Africa.

The objectives were to assess five elite introduced taro genotypes for TLBD tolerance, higher corm yield and plant architecture as well as consumer preferred cooking quality attributes across farmers' field conditions. The study also considered the potential economic feasibility of cultivating the taro genotypes.

Materials and Methods

Five introduced taro genotypes (BL/SM 158, CE/IND 12, BL/SM 151, BL/SM 115 and BL/SM 16), which exhibited potential adaptability to local conditions were evaluated low land on-farm under rain-fed conditions (Table 1) using local variety as check from 2015 to 2017. The planting distance was 1m x 1m.

Table 1: List of locations where on-farm evaluation was carried out

Location	Region	Year
Amposahkrom	Ashanti	2015/2016
Dwendabi	Ashanti	2016/2017
Bomaa	Ahafo	2015/2016
Onwe	Ahafo	2016/2017
Anyinasine	Eastern	2015/2016
Osiem	Eastern	2016/2017
Bonsaso	Western	2016/2016
Pataho	Western	2015/2017
Assin-Asepanaye	Central	2016/2016
Assin-Sekanpodua	Central	2016/2017

Data Collection

The TLBD severity was scored on a scale of 1 - 5; where 1 - no observed symptom, 2 - minimum damage, 3 - average damage, 4 - highly damage, 5 - almost/complete defoliation. The disease incidence indicates the percentage number of plants in the field affected by TLBD. Observed agronomic parameters were plant height, plant girth, number of suckers per plant, harvest index measured as ratio of corm yield to total biomass, corm length, corm circumference and mean corm weight. Sampling of corms for sensory evaluation and corm dry matter content determination was done as reported [19]. The optimum cooking time was determined as reported [20]. Presentation of samples for tasting was completely randomized to rule out bias. Data collection for sensory evaluation was done using a simple total score obtained for colour cards of red, yellow and green given to the assessors, where red card means rejection because it fails in all qualitative attributes of preference and taste; yellow means moderately preferred; and green means highly preferred. For corm dry matter content determination, representative sample of 100 g corm of each genotype was grated and oven dried at 105 °C for 24 hours. Dry matter content was calculated as the ratio of the weight of the dry sample expressed as a percentage of the weight of the fresh sample. Corm yields were determined and partial budget analysis used for the evaluation of profitability of the taro genotypes as follows.

$$\mathrm{NI} = \mathrm{TR} - \mathrm{TC}$$

Where;

NI is net income generated from a taro genotype, TR is the total returns, and TC being the total cost which include the cost of all inputs including labor and capital.

Data Analysis

Data for TLBD was analysed using simple means score for disease severity and mean percentage score for disease incidence. The agronomic data and dry matter content were first subjected to orthogonal comparison between the local taro genotype used as check and the elite taro genotypes. This was followed by Analysis of Variance for traits that showed significance in the contrast and/or genotype but using only data for the elite taro genotypes using split-plot design, where region was allocated to the main plot, genotypes to the sub-plot, and locations within regions as replications. Means separation was done using Tukey Honest Significant Difference (HSD) at 5% significance level. These analyses were carried out using GenStat Release 12.1, and means for traits that showed significance were presented. The mean number of suckers was transformed using the log transformation scale before carrying out the ANOVA. Sensory evaluation was presented graphically and statistically differentiated with error bars using Microsoft Excel Software.

For purposes of partial budget analysis, total cost can be separated into fixed costs (FC) and variable costs (VC) as presented below.

$$\mathrm{TC} = \mathrm{FC} + \mathrm{VC}$$

Where fixed costs (FC) are costs that do not vary between the farmers' variety and the elite taro genotypes and variable costs (VC) are costs that do vary between technologies.

In deciding to adopt a new technology, a farmer would want to know if it would increase his/her net income. The increase or change in net income (ΔNI) is the difference between the change in total returns (ΔTR) and the change in fixed costs (ΔFC) and variable costs(ΔVC). Therefore, change in net revenue (ΔNR) is giving as.

$$\Delta\mathrm{NR} = \Delta\mathrm{FC} - \Delta\mathrm{VC}$$

In addition to net income, another criterion is the benefit cost ratio (BCR), which is useful for evaluating the economics of adopting a new technology. It measures the viability and value that can be derived from investment. It is calculated as.

$$\mathrm{BCR} = \frac{\mathrm{TR}}{\mathrm{TC}}$$

The decision rule is that if the investment has a BCR value greater than one, then the investment can be expected to return a positive net value to farmers when adopted and vice versa.

Results

Generally, the disease pressure was lower in 2016/2017 than 2015/2016. The severity score of TLBD was highest (2.8) at Ahafo region followed by the Ashanti region (2.6), while Central region gave the least score (1.4) for 2015/2016. Similar trend was observed for disease incidence the same year except that the lowest score (10%) was recorded at the

Western region (Table 2). The severity score for 2016/2017 among the locations ranged from 1.6 to 2.5 for Western region and the Eastern region while disease incidence ranged from 19.6% for Ahafo region to 29.7% for the Eastern region (Table 3). Among the taro genotypes, the local variety had the highest mean severity score across years followed by the CE/IND 12 (Tables 2 and 3). Similar trend was true for the disease incidence (Tables 2 and 3).

Table 2: Tolerance of the taro genotypes to TLBD across regions in 2015/2016

Genotype	**Region**										**Mean**	
	Ashanti		**Ahafo**		**Central**		**Eastern**		**Western**			
	***Sev**	**Inc**	**Sev**	**Inc**	**Sev**	**Inc**	**Sev**	**Inc**	**Sev**	**Inc**	**Sev**	**Inc**
BL/SM158	2.0	10	2.5	50	1.5	5	2.5	15	1.5	5	2.0	17
CE/IND 12	3.5	60	4.5	100	1.0	0	4.0	95	1.5	5	2.9	52
BL/SM 115	2.5	55	2.0	60	1.0	0	2.0	60	1.0	0	1.7	35
BL/SM 151	2.0	25	2.0	70	1.0	0	1.5	5	1.0	0	1.5	20
BL/SM 16	2.0	10	2.0	30	1.0	0	1.5	20	1.0	0	1.5	12
LOCAL	3.5	70	4.0	100	3.0	90	3.5	90	4.0	50	3.6	80
Mean	2.6	38.3	2.8	68.3	1.4	15.8	2.5	47.5	1.7	10.0		

*Sev. = severity; Inc.=Incidence (%)

Table 3: Tolerance of the taro genotypes to TLBD across regions in 2016/2017

	Region											
	Ashanti		**Ahafo**		**Central**		**Eastern**		**Western**		**Mean**	
Genotype	**Ser**	**Inc**	**Ser**	**Inc**	**Ser**	**Inc**	**Ser**	**Inc**	**Ser**	**Inc**	**Ser**	**Inc**
BL/SM 158	1.8	14.8	1.3	10	1.3	9.6	1.9	10.5	0.9	5.3	1.4	10.0
CE/IND 12	1.9	12.5	1.5	11.1	1.5	11.4	2.3	36.5	1.1	19.8	1.7	18.3
BL/SM 115	1.8	9.3	1.4	8.6	1.4	8.9	2.0	16,0	1.1	8.0	1.5	10.2
BL/SM 151	1.5	10.3	1.3	14.3	1.3	15.8	2.0	19.5	1.1	8.3	1.4	13.6
BL/SM 16	1.5	7.3	1.2	8.5	1.2	9.2	2.0	19.5	1.1	9.8	1.4	10.9
LOCAL	3.5	95.0	3.5	65.0	4.0	82.0	4.5	76.0	4.0	88.0	3.9	81.2
Mean	2.0	24.9	1.7	19.6	1.8	22.8	2.5	29.7	1.6	23.2		

*Ser. = Severity; Inc. = Incidence (%)

The orthogonal comparison showed significant ($p<0.05$) contrast for number of suckers per plant, high significant ($p<0.01$) contrast for plant height, and highly significant ($p<0.001$) contrast for plant girth, corm yield, corm circumference and mean corm weight (Table 4). However, genotypic differences were significant for all the traits except plant height, number of suckers per plant, harvest index and corm circumference while only plant height, plant girth, harvest index and corm circumference showed no significance ($p<0.05$) for region (Table 4). For the ANOVA of the elite genotypes only, G x E interaction was significant for only plant height as presented in Table 5 and Table 7. No significant differences ($p<0.05$) were observed for region for any of the traits, but differences among the elite genotypes were significant for plant girth, corm yield, mean corm weight and corm dry matter content (Table 5). Plant girth ranged from 23.27 cm to 30.45 cm. These values were given by CE/IND 12 and BL/SM 151. The range of values for corm yield were 7.37 t/ha for CE/IND and 14.78 t/ha for BL/SM 115 while those for mean corm weight and corm dry matter content were 0.737 kg (CE/IND 12) and 1.478 kg (BL/SM 115); and 26.12% (CE/IND 12) and 37.46% (BL/SM 115). BL/SM 115 and CE/IND 12 gave the significantly highest and lowest values for corm yield, mean corm weight and corm dry matter content, but their values were not significantly different from the other elite genotypes. BL/SM 151 and CR/IND 12 recorded the significant highest and lowest plant height but their values were also not significantly different from those of the other elite taro genotypes. These results are presented in Table 6.

Table 4: Mean squares for orthogonal comparison between the local and the elite taro genotypes

Source of variation	**DF**	**Plant height (cm)**	**Plant girth (cm)**	**Number of suckers/plant**	**Harvest Index**	**Corm yield (t/ha)**	**Corm Circumference (cm)**	**Corm length (cm)**	**Mean corm weight (kg)**	**Corm dry matter content (%)**
Rep Stratum	1	2661.0	0.22	0.7369	0.13513	34.74	43.69	15.91	0.3474	13.22
Rep*Units*Strat										
Region	4	1294.0^{ns}	13.24^{ns}	0.4414*	0.07684^{ns}	84.73**	44.92^{ns}	35.29*	0.8473**	285.34***
Genotype	5	2101^{ns}	199.93**	0.1699^{ns}	0.03842^{ns}	161.84***	188.11***	15.01^{ns}	1.6184***	185.29**
Contrast 1	1	7711.0**	707.79***	0.6913*	0.00236^{ns}	504.23***	805.57***	28.40^{ns}	5.0423***	71.23^{ns}
Residual	49	1056.0	44.98	0.1466	0.03833	20.26	29.01	11.34	0.2026	47.42

* $p<0.05$. ** $p<0.01$. *** $p<0.001$. ^{ns} $p>0.05$

Table 5: Mean squares for traits significant for the orthogonal contrast using only the elite taro genotypes

Source of variation	DF	Plant height (cm)	Plant girth (cm)	Number of suckers/plant	Corm yield (t/ha)	Corm Circumference (cm)	Mean corm weight (kg)	Corm dry matter content (%)
Rep Stratum	1	773.0	11.81	0.80783	34.90	6.12	0.3490	0.22
Region	4	1292.7^{ns}	19.80^{ns}	0.33636^{ns}	98.96^{ns}	45.82^{ns}	0.9896^{ns}	240.85^{ns}
Residual	4	5158.5	197.68	1.14457	83.89	79.41	0.8389	254.77
Rep. Region*Genotype stratum								
Genotype	4	698.2^{ns}	72.96*	0.03954^{ns}	76.24**	33.75^{ns}	0.7624*	213.80***
Region*Genotype	16	1016.3*	38.45^{ns}	0.04046^{ns}	14.82^{ns}	27.86^{ns}	0.1482^{ns}	34.23^{ns}
Residual	20	327.8	24.06	0.03083	17.28	26.41	0.1728	17.61

* $p<0.05$. ** $p<0.01$. *** $p<0.001$. ns $p>.05$

Table 6: Plant girth, corm yield, mean corm wight and corm dry matter of the improved taro genotypes

Genotype	Plant girth (cm)	Corm yield (t/ha)	mean corm weight (kg)	Corm dry matter content (%)
BL/SM 115	25.76ab	14.78a	1.478a	37.46a
BL/SM 16	26.21ab	11.99ab	1.1991b	35.94ab
BL/SM 151	30.45a	11.17ab	1.117ab	35.74ab
BL/SM158	24.64ab	9.58ab	0.958ab	31.36bc
CE/IND 12	23.27b	7.37b	0.737b	26.12c
CV (%)	18.8	37.9	37.9	12.6

Sensory evaluation generally showed high preference for four out of the five improved genotypes as the local variety (Figures 1 and 2). The four elite taro genotypes with cooking qualities preferred by the farmers and consumers as the local check were BL/SM 115, BL/SM 151, BL/SM 158, and BL/SM 16.

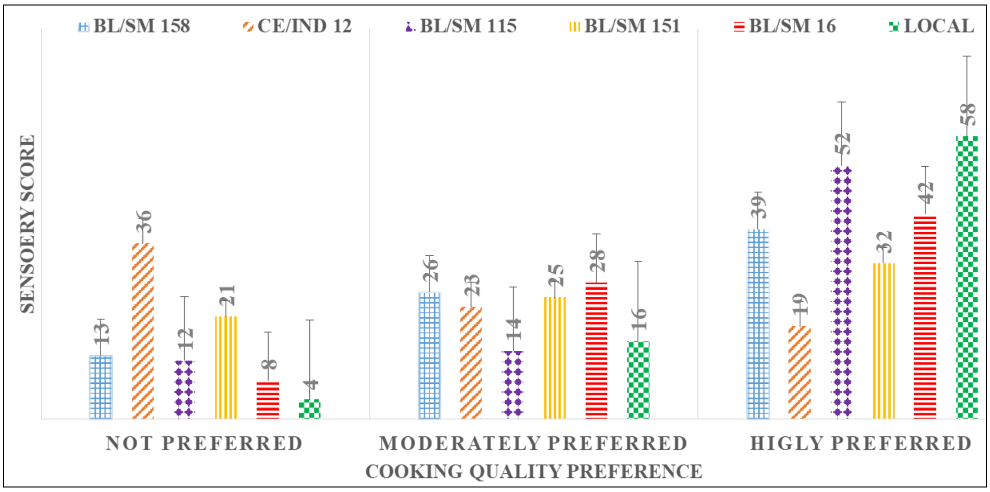

Fig 1: Cooking quality preferences for the taro genotypes across regions in 2015/2016

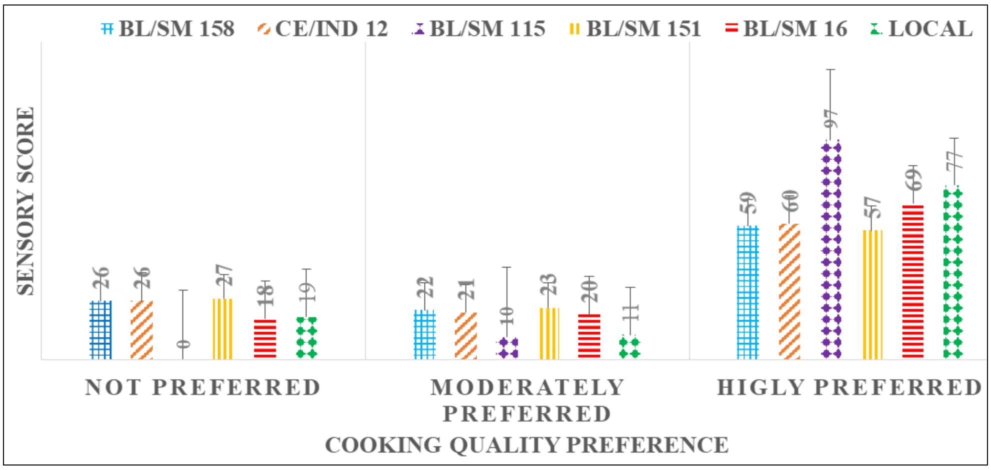

Fig 2: Cooking quality preferences for the taro genotypes across regions in 2016/2017

Generally, the elite taro genotypes gave very good economic outlook compared to the local one, which was the farmer's best-bet (Tables 7 and 8). At farm gate price of Gh¢ 5.00/kg, genotype BL/SM 115 had the highest net benefit value of Gh¢ 56,510.00 followed by BL/SM 16 with net benefit value of Gh¢ 43,955.00 (Table 8). These two elite taro genotypes also had the highest and the second highest net benefit values of Gh¢ 123,020.00 and of Gh¢ 97,910.00, respectively at farm gate price of Gh¢10.00. The local variety had the lowest net benefit value at both prices followed by CE/IND 12. The benefit cost ratio was greater than one for all the genotypes except the local genotype at farm gate price of Gh¢ 5.00, and was also less than two at farm gate price Gh¢ 10.00 unlike the elite taro genotypes which were all greater than five.

Table 7: Partial budget and benefit cost analyses of the taro genotypes

Genotype	BL/SM 158	CE/IND 12	BL/SM 115	BL/SM 151	BL/SM 16	Local
Average yield(kg/ha)	9580	7370	14780	11170	11990	3200
Adjusted yield (kg/ha)	8622	6633	13302	10053	10791	2880
Gross benefit (GHC)	43,110	33,165	66,510	50,265	53,955	14,400
Total variable cost (GHC)	10,000	10,000	10,000	10,000	10,000	10,000
Net benefit (GHC)	33,110	23,165	56,510	40,265	43,955	4,400
Benefit cost ratio (BCR)	3.31	2.32	5.65	4.03	4.40	0.44

*Average yield adjusted 10. Farm gate price = Gh¢5/kg

Table 8: Partial budget and benefit cost analyses of the taro genotypes

Genotype	BL/SM 158	CE/IND 12	BL/SM 115	BL/SM 151	BL/SM 16	Local
Average yield(kg/ha)	9580	7370	14780	11170	11990	3200
Adjusted yield (kg/ha)	8622	6633	13302	10053	10791	2880
Gross benefit (GHC)	86,220	66,330	133,020	100,530	107,910	28,800
Total variable cost (GHC)	10,000	10,000	10,000	10,000	10,000	10,000
Net benefit (GHC)	76,220	56,330	123,020	90,530	97,910	18,800
Benefit cost ratio (BCR)	7.622	5.633	12.302	9.053	9.791	1.88

*Average yield adjusted 10%. Farm gate price = Gh¢10/kg

Discussion

The purpose of on-farm trials in crop improvement is to assess the performance of genotypes in terms of superiority on farmers' field under their production conditions. This creates opportunity for farmers and other stakeholders downstream to be part of the evaluation and selection process. Multilocational trials are usually carried out to evaluate elite genotypes across multiple stress-induce environments for identification and selection of end-user preferred genotypes [21], before their release as commercial crop varieties [22]. Information obtained from such trials are critical for accurate determination and prediction of crop performance in terms of yield stability and genotypic response to environmental variation.

The significant (p<0.05) contrast for the orthogonal analysis for number of suckers per plant, high significance (p<0.01) contrast for plant height, and highly significant (p<0.001) contrast for plant girth, corm yield, corm circumference and mean corm weight indicate that the local taro genotype was significantly lower for these traits compared with the elite genotypes. This implies the superiority of the elite taro genotypes for these traits over the local taro genotype. It further indicates no significant (p>0.05) difference between the local taro genotype and the elite taro genotypes for traits that did not show significance (p>0.05) for the contrast. Thus, for harvest index, it indicates that the relative efficiency of the elite taro genotypes to partition assimilates for corm bulking was not significantly different from that of the local taro genotype, likewise for corm dry matter content for most of the elite genotypes.

Genotypic differences among the taro genotypes for corm yield and corm dry matter content and different response to TLBD indicates that superior genotypes can be identified and selected for higher TLBD tolerance, corm yield and corm dry matter content. Suitability of a crop variety depends on the traits farmers' look for and includes sensory attributes [23], higher yields, and also diseases and pests tolerance. Elite genotypes BL/SM 151, BL/SM 115, BL/SM 16 and BL/SM 158 showed high tolerance to the TLBD than the local genotype and CN/IND 12. The TLBD is the major biotic stress affecting taro production and utilization [8, 24]. The elite taro genotypes per the orthogonal analysis had higher corm yields than the local one, and except for CE/IND 12 whose dry matter content was lower, the other four elite genotypes had comparable or appreciable corm dry matter content as the farmers' best-bet variety, which was the local genotype used as check. Except for CE/IND 12, which was not very much preferred as the farmers' best-bet genotype when cooked, the other four elite taro genotypes were generally highly preferred as the local genotype. In addition to higher corm yields and higher tolerance to diseases and pests, higher corm dry matter is preferred because of suitability for food preparation preferences. Cooking causes changes in physical, chemical and sensory attributes of food [25, 26]. Low dry matter varieties become less mealy when cooked, affecting textural preference traits. They also absorb more oil when fried, which is not cost-effective for processors and also not healthy for consumers. The high or appreciable dry matter content of BL/SM 151, BL/SM 115, BL/SM 16 and BL/SM 158 is an important attribute for meeting the need of consumers in Ghana and West Africa since dry matter content is key trait for root and tuber crops preference in West Africa.

Genotypes usually responds differently in performance in multilocational experiments. This variation in genotypic response is as a results of the interactions between the genotypes and the environment [27, 28], which is referred to as genotype-by-environment interactions (G x E). G × E interaction is important criterion for crop adaptation and development of genotypes with improved end-user traits. Presence of G x E could slow progress in genetic gain [27, 29, 30, 31, 32]. This is because higher precision in selection is realized only when the genotypic effects are efficiently sorted from the environmental effects [33]. The importance of G x E in genotypes evaluation and crop improvement has been reported in many major staple crops [34, 35, 36, 37, 38, 39]. In this study, G x E interaction was not significant for key traits of preference for taro production and utilization such as TLBD, corm yield, corm dry matter content, and number of suckers per plant. This indicates stability in the relative higher performance of the elite taro genotypes across environments for these traits. Thus, apart from farmers benefiting from stable high tolerance of the elite taro genotypes to the TLBD, obtaining higher corm yields and corm dry matter content for their food preference, they will also have adequate planting materials to expand their farms across cultivated environments. Plant height was the only trait that showed G x E interaction and this was due to variation in soil moisture/water content. Mostly water-logged or flooded fields promoted vegetative growth at the expense of corm bulking and cooking quality as the crop's luxury uptake of water reduced its corm yield and corm dry matter content. These imply that the elite taro genotypes do not prefer too much water and prefer muddy or marshy areas. Fields that were previously cultivated to rice also produced lower corm yields and relatively shorter and yellowing or pale green plants. This was due to over exploitation of nutrients as a result of intensive cultivation of rice with little effort to restore soil fertility. Thus, cultivation on previously rice cultivated fields will need application of recommended rates of fertilizer to restore soil fertility for attainment of potential corm yields.

Partial budget analysis is use to analyze practical farm management problems, such as substituting crop enterprises and changing input levels or types of inputs. The partial budget analysis was adapted due to the small changes that were expected to be considered by the farmers [41]. The assumption is that the main objective of a taro producer is to maximize the net income derived from the crop. Net income, generated from a taro crop is the amount of money which is left when the total cost is subtracted from the total returns. The benefit-cost ratio values were far greater than 1 for all the elite taro genotypes compared to the local genotype, which is an indication of positive returns when farmers switch to the elite taro genotypes. The benefit-cost ratio of the elite genotypes showed that if a farmer invests Gh¢ 1.00 in the production of these improved genotypes, he/she will recoup his/her Gh¢1.00 and earn not less than Gh¢2.00 as profit.

Conclusion

The decision to adopt a new cultivar is intricately link to the genotype's response to biotic and abiotic stresses, yield performance as well as consumer taste and preferences. Four of the elite genotypes (BL/SM 158, BL/SM 115, BL/SM 151, and BL/SM 16) shown very high tolerance to TLBD and superior performance for corm yield, corm dry matter content as well as sensory preference compared to the farmers best-bet genotype. Adoption of these four elite taro genotypes as improved cultivars will revive the taro industry which has been in the decline for decades in Ghana and other West African countries due to the out-break of TLBD. These four taro genotypes (BL/SM 158, BL/SM 115, BL/SM 151, and BL/SM 16) were officially released by the National Seed Council of Ghana as commercial varieties in 2019 after recommendation for their release by the National Varietal Release and Registration Committee. Their respective official varietal names in Ghana are BL/SM 158 (*CRI-Huogbelor* meaning Food Security Taro), BL/SM 115 (*CRI-Asempa,* meaning Good News.), BL/SM 151 (*CRI-Agyenkwa*, meaning Saviour), and BL/SM 16 (*CRI-Yen anya woa,* meaning Good to have you).

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