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Evaluation of Pearl millet Varieties for Adaptation to the Semi-Arid Agro-Ecology of Northern Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RALK and PA designed the study, performed the statistical analysis. Author JKB performed the economic analysis. Authors EYA and BIYI performed the experiments and wrote the first draft of the manuscript. Authors, PT, LH and CT carried out the proximate and organoleptic analyses, Authors FAK and MA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Field trials were conducted at the Manga Agricultural Research Station near Bawku in the Upper East Region to evaluate nine genotypes of Pearl millet [*Pennisetum glaucum* (L.) R. Br.] for adaptation to the Sudan Savanna agro-ecology of northern Ghana. The varieties are: Arrow, Bongo Short Head, Bristled millet. SOSAT-C88, Tongo Yellow, GB 8735, ICTP 8203, B9_Tabi and Manga Nara a local check (farmers' variety). The experiment was established as a randomized complete

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block design with 4 replicates. All standard agronomic practices and data collection as recommended for Pearl millet production in Ghana were adhered to. The results indicate highly significant (P<0.001 differences among years and genotypes for all the traits recorded. The local variety Manga Nara was the earliest to reach 50% flowering; whilst SOSAT-C88 was the latest. Downy mildew incidence at 30 days after sowing was least on SOSAT-C88 and ICTP 8203 and highest on the farmers' variety. At maturity downy mildew incidence was highest on Tongo Yellow. Bristled Millet produced the tallest plants whilst Manga Nara, Bongo Short Head and GB 8735 produced the shortest plants. Bongo Short Head produced the broadest spikes whilst B9_Tabi gave the longest spikes. Pearl millet harvest indices were generally low with Arrow and ICTP 8203 producing the highest and GB 8735; Bongo Short Head and the farmers' variety the lowest. ICTP 8203, SOSAT-C88 and Bristled Millet recorded higher grain yields than the other genotypes evaluated. The farmers' variety, GB 8735 and B9_Tabi recorded the lowest grain yields compared to the trial mean. SOSAT-C88 produced superior straw yield compared to the other genotypes whilst Tongo Yellow; the farmers' variety, Arrow and GB 8735 produced appreciably lower straw yields. ICTP 8203, SOSAT-C88 and Bristled Millet were the most efficient whilst the farmers' variety was the least efficient in rainwater capture and use.

Keywords: Bio-fortified varieties; early millet; Pennisetum glaucum (L.) R. Br; Sudan savanna agro-ecological zone.

ABBREVIATIONS

ANOVA- analysis of variance; arrow- AR; bongo short head- BSH; bristled millet- BM; days after planting– DAP; downy mildew incidence– DMI; manga nara– MN; randomized complete block design–RCBD; SOSAT-C88– SOSAT; tongo yellow–TY; upper east region –UER.

1. INTRODUCTION

The importance of pearl millet [*Pennisetum glaucum* (L.) R. Br.] is most pronounced in the Upper East Region where it serves as a hunger-breaker immediately after the long dry season, when most farm-families would have exhausted their scanty harvest and even have difficulties purchasing seed for the incoming cropping season [1]. Pearl millet is the only cereal that reliably provides grain and fodder under dryland conditions on shallow and sandy soils with low fertility and low water holding capacity [2,3].

While pearl millet farmers have managed to feed their families under harsh environmental conditions of the Sudan Savanna for centuries, high population pressure in recent times is outstripping the capacity of this environment to meet new demands of food, fuel wood and an occasional additional income using current farmers' agronomic practices and now severely challenged old varieties such as Manga Nara. The only cereal crop that can be sown and harvested within 3 months in the UER of Ghana is pearl millet. Regrettably, there have not been any improved pearl millet varieties released since Ghana's independence from colonial rule in the mid 1950s.

The most important characteristic of pearl millet is the crop's unique ability to tolerate and survive under adverse conditions of continuous or intermittent drought as compared to most other cereals like maize and sorghum [4]. Pearl millet is characterized by the C4-cycle photosynthetic pathway and has a very high rate of biomass production, despite being a crop adapted to the drier parts of the semi-arid tropics. Its northern limit in West Africa is the Sahelian zone receiving about 250 mm annual rainfall, where cultivars requiring only 55-65 days to mature are grown [5].

The only pearl millet variety that was bred during the colonial era and released was Manga Nara, which is currently being cultivated extensively in the UER. This is because pearl millet for a long period of time has not officially received the recognition it deserves as a strategic crop with almost unrivalled potential in respect of exceptional nutrition capacities [6,7,8]. The Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI) initiated a pearl millet breeding program in the latter part of the 1990s. Scientists selected early maturing, pest and disease resistant pearl millet varieties, which have been widely evaluated with farmers through on-farm adaptive trials and demonstrations and are now being presented to the National Variety and Technical Committee for consideration for release to increase pearl millet productivity and production in Ghana.

Adoption of improved pearl millet varieties tends to be slow in some regions due a complex of factors such as seed availability, variety performance or household preferences [9]. The ability of pearl millet to reliably produce on marginal lands and under low rainfall makes it an attractive choice for sandy, low fertility and acidic soils [10]. There are two schools of thought in plant breeding: one is of the view that selecting for broad adaptation has greater gains and stability whilst the second believes that in developing crops such as pearl millet that are grown as landraces and also produced in marginal areas, site-specific breeding is of essence [11,12]. Either way, the importance of improved pearl varieties for enhanced yields cannot be over emphasized. Indeed earlier works have shown the benefits of heterozygosity and hybrid vigor in pearl millet and sorghum in Africa [13-16].

The introduction of five new promising pearl millet cultivars together with three additional biofortified varieties is therefore welcome news to the anxious small holder farmers of the Upper East Region, who over the years have always ranked 'the lack of early-maturing, pest- and disease-resistant or -tolerant varieties' as the second most important constraint, rated only after 'low soil fertility', to enhanced crop productivity in the area [17]. The inclusion of biofortified varieties in the study was to help address the problem of malnutrition among children and nursing mothers [18,19] in the region. The objective of this study was to test the performance of these pearl millet varieties for adaptation to the agro-ecological and socio-economic conditions of the Upper East Region of Ghana.

2. MATERIALS AND METHODS

2.1 The Experimental site

Field trials were established during the rainy seasons of 2012 and 2013 at the Manga Agricultural Research Station near Bawku (11°01' N, 0°16' W, 249 m above sea level) in the Sudan Savanna agro-ecological zone of northeastern Ghana. The annual mean rainfall of the experimental site is approximately 950 mm. Rainfall there is monomodal and has a characteristic erratic distribution pattern. The rains usually start in April, peak in August and end in October. There is a recurrent dry spell in July.

The soils in the Sudan Savanna zone of Ghana are developed over granites and stones. The topsoils are light, varying in texture from coarse sands to loams. The texture of the soils varies from loamy sand, sandy loam to loam and pH of these soils ranges from 5.4 to 6.1. Plant nutrient status is generally below average [8] , Table 1.

The study evaluated nine pearl millet varieties comprising of three biofortified, five other improved millet varieties (previously evaluated in the region by the CSIR-SARI) together with a local improved cultivar called Manga Nara [20-23,18]. The land on which the trial was established had been used for seed maize multiplication for the past four years. Cow dung at a rate of 4 t/ha was applied to the field just before disc harrowing with a tractor. The experiment was established in a RCBD with four replicates. Plot dimensions were 4.5 m x 5 m. Sowing was done on ridges constructed by bullock traction with a spacing of 0.75 m. Seeds were sown on the middle of ridges with 0.30 m spacing between hills. Pearl millet was sown 3 to 4 seeds per hill and thinned out to 2 plants per hill at 2 weeks after planting (WAP). First weeding was done 2 WAP prior to the first (basal) fertilizer application. The second fertilizer application was performed 2 weeks after the basal fertilizer application. Fertilization was at the following rates: basal - 40 kg N/ha and 40 kg/ha each of P_20_5 and K_20 immediately after thinning using compound fertilizer (NPK 15-15-15) and topdressing using ammonium sulphate. Re-shaping of ridges (using bullocks) was done after topdressing to prevent root lodging as recommended for cereal cultivation in the Sudan Savanna agro-ecological zone [4,17].

All recommended data for pearl millet production [4] were collected including attainment of 50% bloom (days), plant height at maturity (cm), spike length (cm), spike girth (mm), downy mildew incidence at 30 days after seedling emergence (% of hills), downy mildew incidence at maturity (% of hills) and Harvest index . Rainwater use efficiency (kg mm^{-1} ha^{-1}) was determined as the ratio of rain water received in the season to crop yield. The data obtained were subjected to statistical analysis using *GenStat* 9^{th} Edition software [24]. Where statistical significance was detected, means were separated using the standard error or standard error of a difference between means.

2.2 Organoleptic Evaluation

Organoleptic attributes (mouth-feel, taste and texture) influence the acceptability of bread made from millet-wheat composite flour. These were evaluated by a team comprising farmers and end users of bread (from composite flour) for overall acceptability on a scoring basis of 1 (not acceptable), 5 (fairly acceptable) to 9 (highly acceptable).

2.3 Economic Analyses

Economic analyses were performed to compare the profitability of producing different varieties of millet in the semi-arid agro-ecology of northern Ghana using the same inputs. The crop enterprise budget technique was used [25] where the *benefit-cost* ratio of millet varieties were used to assess the profitability (or lack thereof) of the different varieties. The cost of all recommended variable inputs used in the study were considered. Crop prices and all input prices were surveyed in the study area using seasonal averages that prevailed in the study area during the cropping seasons.

The value of the millet grain was taken at harvesting periods and therefore there was no cost borne for storage. Though stover has great importance as fuel wood in the UE Region of Ghana economic analyses did not cover this. Variable costs were the actual input prices paid by farmers each year, which included the different types of fertilizers, cost of harvesting, carting, threshing, winnowing and bagging grain. Net returns per hectare were then calculated as the difference between the gross income and total variables costs. The benefit-cost ratio was therefore calculated by dividing the benefits by the total variable costs as:

$$\mathrm{B/C} = \frac{\mathrm{TB}}{\mathrm{TVC}}$$

Where

B/C- Benefit Cost Ratio
TB - Total Benefit
TVC-Total Variable Cost

When B/C ratio is = 1.8, it implies that for each 1 GH₵ invested in an enterprise, the farmer will recover his 1 GH₵, plus an extra 0.8 GH₵ as net benefit. All other things being equal, farmers should be willing to accept a variety if the B/C ratio of that variety is greater than the minimum acceptable B/C rate of 1 (B/C >1). An enterprise with a ratio greater than 1 (B/C >1) is economically viable.

3. RESULTS

The soils of the experimental site are mainly sandy, and also acidic with high levels of potassium. However, the soil levels of all the other nutrients required for plant growth were below average for enhanced cereal production Table 1 [8].

Table 1. Some physical and chemical properties of the surface (0-15 cm) soil at the experimental site at manga agricultural research station, 2012

Soil physical and chemical properties	Value
Sand (%)	80.4
Silt (%)	16
Clay (%)	3.6
Soil texture	Loamy sand
Soil pH	4.64
Organic carbon (%)	0.35
Total nitrogen (%)	0.06
Available P (mg kg^{-1})	13.58
Exchangeable cations [cmol (+) kg^{-1}]	
Ca	0.07
Mg	0.05
K	65.70
CEC [cmol (+) kg^{-1}]	3.28

The tallest plants were produced by B9_Tabi followed closely by Bristled Millet and then SOSAT, whilst the shortest plants were recorded by the farmers' variety, BSH and GB 8735 (Table 2). B9_Tabi, Bristled Millet and SOSAT produced significantly (P<0.001) taller plants than the rest of the genotypes evaluated in the study.

The farmers' variety, Manga Nara (MN) was the earliest to reach 50% flowering whilst SOSAT was the latest to attain this stage. MN attained 50% flowering significantly earlier than the rest of the varieties tested. Similarly Tongo Yellow, GB 8735, BSH and Arrow all attained 50% flowering significantly earlier than SOSAT and B9_Tabi (Table 2). There however, were no significant differences among treatments with regards to the number of panicles harvested. Nonetheless, ICTP 8203 recorded the highest number of panicles harvested followed by B9_Tabi and SOSAT. GB 8735 recorded the lowest number of panicles harvested. Only ICTP 8203 and B9_Tabi recorded harvested panicles numbers that were above the trial mean.

Downy mildew incidence (DMI) at 30 days after sowing was highest on GB 8735 and on the farmers' variety, whilst SOSAT recorded the lowest level of infection followed by ICTP 8203. The local improved varieties (Fig. 1) had lower levels of infection as compared to that recorded for the trial mean. At maturity, the levels of downy mildew incidence was similar to that observed at 50 days after sowing with GB 8735 recording the highest level of DMI incidence followed by Tongo Yellow; whilst SOSAT and ICTP 8203 again recorded the lower levels of infection (Table 2). Significant (P<0.001) differences were noted among the varieties with regards to DMI or the number of 'green ears' recorded at harvest with the farmers' variety recording significantly the highest number 'green ears' whilst B9_Tabi and SOSAT recorded the lowest numbers of 'green ears'. B9_Tabi, SOSAT and ICTP 8203 all recorded significantly lower numbers of 'green ears' than that recorded by the farmers' variety (Table 2).

There were significant (P<0.001) differences among genotypes with regards to spike length with B9_Tabi producing the longest spikes (panicles or ears) followed closely by Bristled Millet whilst BSH and the farmers' variety produced the shortest spikes at harvest. The spikes produced by all the varieties were significantly longer than those produced by BSH and Manga Nara (Table 3). Spike girth however followed a different trend, with the Bongo Short Head producing the broadest spikes and B9_Tabi the thinnest. BSH produced significantly broader spikes than the rest of the varieties tested. Similarly, SOSAT, MN, TY and GB 8735 all produced significantly broader spikes than those produced by B9_Tabi, ICTP 8203, Bristled Millet and Arrow (Table 3).

s/no	Improved varieties	Bio-fortified Varieties	Local/ 'landrace' variety (check)
1	Arrow (AR)	GB 8735 [17]	Manga Nara (MN)
2	Bongo Short Head (BSH)	ICTP 8203 [18,19]	
3	Bristled Millet (BM)	B9_Tabi [20]	
4	SOSAT- C88		
5	Tongo Yellow (TY)		

Fig. 1. Improved pearl millet varieties evaluated

Table 2. Time required to reach 50% flowering, plant height at harvest and downy mildew incidence as affected by pearl millet genotype in field trials at SARI-manga during the 2012-2013 cropping seasons

Millet genotype	Time required to reach 50% flowering (days)		Plant height at harvest (cm)		Downy mildew (%) at 30 days		Downy mildew (%) at maturity	
	2012	2013	2012	2013	2012	2013	2012	2013
Arrow	50^{c†}	45^{b}	202.5^{bc}	210^{cd}	6.75^{b}	0.25^{a}	23.3^{c}	1.0^{a}
Bongo Short head	49^{c}	46^{b}	189.6^{ab}	195^{b}	7.25^{bc}	0.00^{a}	29.3^{d}	1.75^{a}
Bristled Millet	53^{d}	52^{c}	243.8^{e}	234^{e}	5.75^{b}	1.00^{a}	21.3^{c}	1.25^{a}
GB 8735	48^{b}	46^{b}	191.3^{e}	198^{bc}	17.25	1.80	34.0	6.25^{c}
ICTP 8203	51^{c}	56^{d}	215.6^{cd}	199^{b}	4.00^{ab}	0.0^{a}	9.5^{b}	2.50^{b}
SOSAT	58^{d}	58^{d}	228.5^{d}	210^{c}	0.25^{a}	0.00^{a}	1.75^{a}	0.50^{a}
B9_Tabi	55^{d}	65^{e}	246.7^{e}	221de	11.0^{c}	0.00^{a}	23.3^{c}	0.0^{a}
Tongo Yellow	46^{b}	46^{b}	212.4^{c}	204^{b}	9.25^{cd}	0.00^{a}	30.3^{d}	3.75^{b}
Manga Nara	43^{a}	41^{a}	185.7^{a}	176^{a}	11.75^{d}	1.00^{a}	23.1^{c}	6.75^{c}
Mean	50.3	51	212.9	205	8.14	0.44	22.3	2.64
LSD $_{(0.01)}$	2.90	3.61	13.64	14.77	4.14	1.20	4.52	2.14

† *Values with the same letter are not significantly different at P≤0.05*

Table 3. Spike length (cm), spike girth (mm) and harvest index as affected by pearl millet genotype in field trials at SARI-manga during the 2012-2013 cropping seasons

Millet genotype	Spike length (cm)		Spike girth (mm)		Harvest Index	
	2012	2013	2012	2013	2012	2013
Arrow	21.3^{b†}	26.9^{cd}	73.5^{ab}	74.5	0.09^{c}	0.12^{c}
Bongo Short Head	13.6^{a}	13.4	114.5	77.0	0.07^{ab}	0.09^{b}
Bristled Millet	30.5^{d}	33.1	77.0^{b}	113.0	0.08^{bc}	0.10^{bc}
GB 8735	24.3^{b}	24.6^{bc}	90.0^{c}	98.0	0.06^{a}	0.10^{bc}
ICTP 8203	26.2^{cd}	27.3^{c}	77.0^{b}	79.0	0.09^{c}	0.08^{ab}
SOSAT-C88	22.6^{bc}	22.3^{ab}	98.5^{d}	97.0	0.07^{a}	0.08^{ab}
B9_Tabi	33.9	29.4^{d}	68.5^{a}	67.0	0.07^{a}	0.05^{a}
Tongo Yellow	20.5^{b}	21.0^{a}	91.0^{c}	90.5	0.09^{c}	0.12^{c}
Manga Nara	15.9^{a}	18.7^{a}	96.5^{cd}	100.0	0.07^{a}	0.09^{b}
Mean	23.8	24.02	87.4	88.4	0.08	0.092
LSD $_{(0.01)}$	4.35	4.36	7.43	0.95	0.01	0.034
CV (%)	12.5	12.4	5.81	7.30	21.30	25.30

†*Values with the same letter are not significantly different at P≤0.05*

Harvest index of millet on the average was generally much lower than those reported for other cereals such as maize, rice and sorghum [13, 15] with Arrow, ICTP 8203 and Tongo Yellow recording the highest harvest indices whilst GB 8735 recorded the lowest. Arrow, ICTP 8203 and TY recorded significantly (P<0.001) greater harvest indices than those recorded by GB 8735 (Table 3). 100-grain weight of pearl millet was similarly very low as compared to values reported for its dry cereal counterparts with Bristled Millet and Tongo Yellow recording the heavier grain than those produced by B9_Tabi and Arrow. Grain yield of pearl millet was significantly (P<0.01) influenced by variety with ICTP 8203 producing the highest grain yield, followed closely by SOSAT and Bristled Millet whilst the farmers' variety and GB 8735 produced the lowest. ICTP 8203 produced significantly higher grain yield than all the treatments except SOSAT and Bristled Millet. SOSAT also significantly out-yielded Manga Nara, GB 8735; and B9_Tabi. Bristled Millet significantly out-performed the farmers' variety and GB 8735. All the varieties evaluated produced greater grain yield than the trial mean of 1 metric ton with the exception of GB 8735, B9_Tabi and MN. SOSAT produced the highest straw yield followed closely by B9_Tabi whilst, Tongo Yellow produced the lowest (Table 4). SOSAT produced superior straw yield than the rest of the treatments except B9_Tabi. All of the varieties significantly out-yielded the Tongo Yellow. All the varieties with the exception of TY Arrow, MN and GB 8735 produced lower straw yield than to the trial mean yield.

Rainfall use efficiency (RUE) is a measure of how efficiently the genotype uses rain water. RUE was significantly (P<0.01) affected by genotype with ICTP 8203 recording the highest RUE followed closely by SOSAT and Bristled Millet. ICTP 8203 recorded significantly higher RUE than that recorded for the farmers' variety, GB 8735, Tongo Yellow and Arrow (Table 4). Only ICTP 8203, SOSAT and Bristled Millet recorded RUE values greater than the trial mean.

Organoleptic attributes, which influenced the acceptability of bread made from millet-wheat composite flour, are presented in Table 5. As shown, mouth-feel, taste and texture contributed significantly and correlated positively with overall acceptability. Even though they are essential attributes, and may affect acceptability of other products, appearance, color, aroma and crust did not significantly influence panelists' preference for bread made from millet-wheat composite flour. The performance of the different millet varieties in the final product, with respect to the key sensory attributes was quite promising, since a mean score of 5.8 (mouth-feel), 5.8 (taste), 5.7 (texture) were obtained for these attributes. Bread made from composite flour from the 5 different varieties showed no significant differences (P<0.05) for these sensory indices (Table 6). This indicates that millet-wheat composite flour from these pearl millet varieties can be used in the production of bread with acceptable mouth-feel, taste and texture.

From Table 7 Below almost all pearl millet varieties tested are economically feasible with the exception of B9_Tabi which gave a B/C ration of 0.82.

Table 4. 100-grain weight (g), grain yield (kg/ha), stover yield (t/ha) and water use efficiency (kg mm^{-1} ha^{-1}) as affected by pearl millet genotype in field trials at SARI-manga during the 2012-2013 cropping seasons

Millet genotype	100-grain weight (g)		Grain yield (kg/ha)		Stover yield (t/ha)		Rainwater use efficiency (kg mm^{-1} ha^{-1})	
	2012	2013	2012	2013	2012	2013	2012	2013
Arrow	9.2^{bc†}	13.1^{c}	1039^{b}	2131^{c}	15.8^{a}	15.8	1.84^{b}	3.30
Bongo short head	9.5^{c}	10.9^{b}	1046^{b}	1188^{a}	21.7^{c}	13.2^{a}	1.85^{c}	1.80^{a}
Bristled millet	11.5^{d}	15.1^{d}	1255^{c}	2022^{bc}	22.9^{c}	10.9^{a}	2.22^{d}	3.10^{b}
GB 8735	9.8^{c}	13.6^{cd}	756^{a}	1519^{b}	19.3^{b}	11.6^{a}	1.34^{ab}	2.40^{b}
ICTP 8203	8.4^{b}	9.2^{a}	1492	1344^{a}	23.8^{d}	13.1^{a}	2.64^{e}	2.10^{a}
SOSAT-C88	7.1^{a}	11.4^{b}	1307^{c}	2069^{c}	30.1^{f}	19.8	2.31^{d}	3.20^{a}
B9_Tabi	6.2^{a}	7.7^{a}	922^{ab}	972^{a}	28.3^{e}	16.8	1.63^{bc}	1.50^{a}
Tongo Yellow	11.4^{d}	15.0^{d}	1027^{b}	1896	11.8	13.0^{a}	1.82^{c}	2.90^{b}
Manga Nara	10.0^{c}	14.2^{c}	713^{a}	1296^{a}	15.1^{a}	11.20^{a}	1.26^{a}	2.00^{a}
Mean	9.21	12.3	1062	1604	21.5	13.9	1.88	2.5
LSD $_{(0.01)}$	0.92	1.50	184.7	528.9	1.70	3.00	0.327	0.82
CV (%)	1.90	8.4	38.1	22.6	13.64	14.8	24.60	22.6

† Values with the same letter are not significantly different at P≤0.05

Table 5. Attributes affecting acceptability of bread produced with blended flours of pearl millet and wheat

Parameter†	Acceptability estimates	SE of estimates	P-value
Intercept	-0.252	0.116	0.038
Mouth-feel	0.233	0.180	0.035*
Taste	0.372	0.118	0.004*
Texture	0.347	0.148	0.027*

**significantly different at P≤0.05. †appearance, color, aroma and crust were excluded from the model because they were not influential predictors of bread acceptability*

Table 6. Comparison between influential attributes from different pearl millet varieties

Variety	Attribute		
	Mouth-feel	Taste	Texture
Arrow	6.4±0.6[a]	6.3±0.6[a]	6.3±0.5[a]
Bristle millet	5.7±0.5[a]	5.6±0.6[a]	5.5±0.6[a]
Bongo Short Head	5.4±0.7[a]	5.4±0.7[a]	5.4±0.7[a]
Tongo Yellow	5.8±0.6[a]	6.0±0.6[a]	5.8±0.6[a]
SOSAT	5.7±0.7[a]	5.7±0.7[a]	5.7±0.7[a]

[†]Values with the same letter are not significantly different at P≤0.05

[1]Table 7. Comparing the economic returns of pearl millet varieties for adaptation to the semi-arid agro-ecology of northern Ghana

Treatment	Arrow	Bongo short head	Bristled millet	GB 8735	ICTP 8203	SOSAT	B9_tabi	Tongo yellow	Manga nara
Yield/ha (kg)	2131	1188	2022	1519	1344	2069	972	1896	1296
Price/kg (GH₵)	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8
Gross Benefit (GH₵)	1917.9	1069.2	1819.8	1367.1	1209.6	1862.1	874.8	1706.4	1036.8
Cost/ha (GH₵)									
Ploughing	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5	87.5
Cost of Seed	15	15	15	15	15	15	15	15	12
Cost of Herbicide	35	35	35	35	35	35	35	35	35
Fertilizer: NPK $_{15-15-15}$ (NPK)	357.5	357.5	357.5	357.5	357.5	357.5	357.5	357.5	357.5
Fertilizer: Sulphate of ammonia (S/A)	143	143	143	143	143	143	143	143	143
Harvesting	50	50	50	50	50	50	50	50	40
Carting	60	60	60	60	60	60	60	60	55
Threshing	120	120	120	120	120	120	120	120	110
Winnowing and Bagging	50	50	50	50	50	50	50	50	45
Labour	150	150	150	150	150	150	150	150	130
Total Variable Cost (GH₵)	1068	1068	1068	1068	1068	1068	1068	1068	1015
Net Benefit	849.9	1.2	751.8	299.1	141.6	794.1	-193.2	638.4	21.8
B/C Ratio	1.80	1.00	1.70	1.28	1.13	1.74	0.82	1.60	1.0

4. DISCUSSION

There were strong positive correlations between plant height and spike length with pearl millet grain yield. Similar results have been reported in earlier evaluation of pearl millet varieties in Ghana [26] and across seven countries in West Africa [27]. The low incidence of downy mildew on SOSAT-C88 and ICTP 8203 can be ascribed to their resistance to the disease, whilst the farmers' variety and the other improved varieties were all more or less susceptible to the disease. These findings are corroborated by those of [27,28] who reported lower incidence of downy mildew on SOSAT and higher infection scores on the local improved open pollinated varieties.

Time required to reach 50% flowering influenced pearl millet grain yield with higher grain yield being associated longer days to attainment of 50% flowering. This could be due to longer periods of utilization of plant growth resources such as nutrients; soil moisture and solar radiation.

[1]Average of prices (GH₵) surveyed within the project area for (2013): price millet/kg (0.90- new Improved varieties and 0.80 - MN); Price NPK /kg (1.43); Price SA /kg (0.96); Average daily wage rate (5.00 GH₵); price of threshing per 100kg bag (5.00); Price of winnowing/100kg bag (2.50); price of seed/kg [1.50 (new varieties),1.20 (Manga Nara)]
1.0 US$ = approx. 3.2 (GH₵) on November 25, 2014

Time required to reach 50% flowering had the least consistent correlation with grain yield [3,26]. The higher yields associated with ICTP 8203, SOSAT and Bristled Millet was due to their low numbers of "green ears" which are formed when the downy mildew pathogen systemically infects the developing panicle so that the host plant's reproductive structures are replaced by leaf-like structures containing the oospore that are involved in survival of the pathogen in the soil from one cropping season to the next [29,30].

The higher yielding varieties recorded greater harvest indices indicating their superior conversion of dry matter to generative at the expense of vegetative organs as reflected in the greater harvest indices associated with the higher yielding varieties compared to their lower yielding counterparts. The higher grain yields associated with the top high yielding varieties comprising ICTP 8203, SOSAT, Bristled Millet, Bongo Short Head and Arrow could be attributed to their relatively higher rain water use efficiencies thereby resulting in better resource capture and use of nutrients [31] and solar radiation with resultant of dry matter accumulation. Improved pearl millet seed costs more than the farmers' own saved seed but research and extension have demonstrated repeatedly to farmers in northern Ghana that the cost component of cereal seed in a crop budget is relatively small (about 2%), and it pays to use improved certified seed [32]. The higher cost of newly introduced improved seed and possible crop failure in marginal (droughty) years with the use of longer duration higher yielding hybrids are critical issues which cannot be lost on researchers and farmers alike. This work seeks to enhance farmers' available choices in pearl millet varieties taking their specific financial and local situations into consideration.

Straw yield followed a trend like that of grain yield with the better performers also producing higher straw yields compared to their lower yielding counterparts. Pearl millet varieties are not only a great source of starch, making them a high-energy food source. They are also a source of protein, fiber, omega-3 fatty-acids, and mineral micro-nutrients like iron and zinc, as well as the mineral macro-nutrients and a rich source of phosphorus, which plays an important part in the structure of body cells. The importance of stover from pearl millet, sorghum or maize for fuel-wood cannot be over-emphasized. Indeed economic trees in the study area such as sheanut (*Vitellaria paradoxa*) and dawadawa (*Parkia biglobosa)* are zealously protected from being cut for charcoal and fuel wood thus stover from pearl millet comes as a very important supplementary source of fuel-wood.

The varieties Arrow, SOSAT-C88 and Bristled Millet have relatively high B/C ratios of 1.80, 1.74, 1.70 respectively. These three varieties will easily be accepted by farmers to replace their current farmer variety which has a B/C ratio of 1.0. Many authors [9,33] are of the mind that in the next decade or so, the greatest advances in agriculture in the warmer climatic regions of the world will come from the development of pearl millet as a feed grain crop.

5. CONCLUSION/RECOMMENDATIONS

These preliminary results have clearly shown the superiority of SOSAT-C88, Bristled Millet, Bongo Short Head, Arrow and Tongo Yellow compared to the widely grown but very old improved pearl millet variety Manga Nara. These varieties would be included as inspection materials in the coming seasons for evaluation by the National Variety Release and Technical Committee for release to farmers in order to increase both yield and areas of cultivation of the crop, which has lost grounds to maize cultivation in recent times due to the lack of improved high yielding varieties.

There is also the need to breed for downy mildew resistance in the local improved varieties, which all recorded relatively high levels of the disease in the present study.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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