



Performance of Pro-Vitamin A Maize Synthetics and Hybrids Selected for Release in Ghana

Manfred B. Ewool, Richard Akromah¹ and Patricia P. Acheampong

Crops Research Institute, P. O Box 3785, Kumasi, Ghana

¹Department of Crop Science, Kwame Nkrumah University of Science and Technology Kumasi, Ghana

ABSTRACT

Vitamin A deficiencies are serious forms of malnutrition that retard growth, weaken the immune system and may also cause blindness. Orange maize varieties may contain high levels of this nutrient in its natural form and when ingested, become available to the body for metabolic processes. The traditional system of variety release in Ghana involves multi-location and on-farm testing, morphological descriptions, physico-chemical properties determination, consumer preferences and economic analysis. Multi-location trials involving Pro-vitamin A (PVA) synthetics and hybrids were established at 7 locations in 2013 and 2014 major and minor seasons given a total of 12 and 13 environments respectively for the hybrids and synthetics. GGE biplot analysis revealed that PC1 and PC2 explained 88.31% and 86.09% of the total variation in the PVA hybrids and synthetics respectively. Based on superiority and stability, the biplot indicated that the best PVA synthetic maize genotype was PVA SYN 13 and this had a potential yield of 4 t/ha and pro-vitamin A content of 9.3 µg/g and in the case of the hybrids, these were LY1001-14, LY 1001-10 and LY 1001-22 and had potential yields of 6.0 t/ha, 6.1 t/ha and 5.4 t/ha and pro-vitamin A contents of 9.2 µg/g, 11.3 µg/g and 8.5 µg/g respectively. Economic analysis showed that benefit cost ratios were 3:1, 2.13:1 and 2.10:1 for LY1001-14, LY1001-10, and PVA SYN 13 respectively in 2013 and 1.33:1, 3.26:1 and 1.33:1 for the same varieties respectively in 2014. It was concluded from the study that the new maize varieties were high in productivity and pro-vitamin A contents and would increase farmers' incomes, improve food security and help solve malnutrition problems when adopted by farmers.

Key Words: Malnutrition, Immune System, Blindness, Orange Maize, Metabolic Processes, Benefit Cost Ratios, GGE Biplot

1. INTRODUCTION

Vitamin A plays several crucial roles in the human body. In the retina of the eyes, it is needed for the adaptation to darkness. Besides that, vitamin A is important in all body tissues to maintain growth and health of cells. In particular, epithel cells are affected by lack of vitamin A, leading to a weakening of the immune system and to irreversible blindness due to eye lesions. Vitamin A deficiency (VAD) affects 100 to 140 million children worldwide with 250,000 to 500,000 children having night blindness and several children standing the risk of being severely affected by measles, tuberculosis, diarrhoea and other illnesses and thus have a higher mortality risk (FAO 1997, FAO/WHO 2002, WHO 2003). The high prevalence of VAD in Ghana is partly attributed to low bio-available Vitamin A in the predominant cereal, root, and tuber crops based foods consumed by adults as well as infants. Moreover, poverty makes it virtually impossible for the majority of Ghanaians to afford animal sources of Vitamin A. Maize is the most important cereal staple in Ghana and other countries in sub-Saharan Africa. It is consumed in many ways in these countries without adequate protein or micronutrient supplement, resulting in widespread malnutrition. It is often the first major supplementary food fed to infants from as early as age 2 to 3 months without any additional protein or micronutrient in the diet at this vulnerable age. Breastfeeding in infants is a natural source of vitamin A and this is a crucial component of

childhood. Thus, promoting breastfeeding is the best way to protect babies from VAD. For deficient children, the periodic supply of high-dose vitamin A in swift, simple, low-cost, high-benefit interventions has also produced remarkable results, reducing mortality by 23% overall and by up to 50% for acute measles sufferers. However, because breastfeeding is time-limited and the effect of vitamin A supplementation capsules lasts only 4-6 months, they are only initial steps towards ensuring better overall nutrition. A long-term solution to VAD is planting the "seeds" or cultivating the garden. Food fortification takes over where supplementation leaves off. Food fortification, for example sugar in Guatemala, maintains vitamin A status, especially for high-risk groups and needy families. In Africa and South-East Asia, growing fruits and vegetables in home gardens complements dietary diversification and fortification and contributes to better lifelong health (WHO 2016). Researchers are working hard to develop new crop varieties high in pro-vitamin A.

In order to make new varieties available to farmers in Ghana, there is a traditional system of variety release. This involves at least 2 years testing of the varieties in multi-location and on-farm, morphological descriptions, physico-chemical properties determination, consumer preferences and economic analysis if new varieties are to be adopted. Superior varieties are grown by

researchers for inspection by the variety release committee. At least two inspections are usually conducted (vegetative and at harvest). The leader of the Research team would normally make a data presentation to the release committee and a final document presented to the committee prior to the release. Since multi-location testing involves planting different genotypes in a number of locations and seasons, Genotype by Environment (GE) and their interaction (I) analysis is employed. Genotype by Environment interaction (GEI) is very important in breeding improved varieties and may be defined as changes in the relative performance of genotypes across different environments (Walter 1993). Large GEI could occur when the crop is tested throughout a region with a number of different and special environments (Allard & Bradshaw 1963) and significant differences in GE may suggest location specific variety development. Differences in years, seasons and locations may contribute to GEI (Akposoe 1971). For example, Akposoe (1975) observed significant variety x fertilizer interactions in maize evaluations at Wenchi and Yendi in the transition and Guinea Savanna zones of Ghana respectively. Badu-Apraku et al. (2003) also evaluated 10 early maturing maize varieties from 1996 to 1998 in 10 locations representing 30 environments and observed that varieties, environments and GEI were highly significant. Sallah et al. 2004 observed significant GEI in 3 maturity groups of maize, evaluated for grain yield in 32-36 environments. Kpotor et al. (2014) recently assessed maize hybrids and open pollinated varieties at Kwadaso and Ejura in the forest and forest- transition zones of Ghana respectively and revealed significant interactions for genotype by location (G x L), genotype by nitrogen (G x N) and G x N x L for grain yield. Significant GEIs have been observed in other crops including groundnut, chickpea and wheat (Mercer-Quarshie 1980; Arshad et al. 2003; Sial et al. 2000). However, it has been indicated that where rainfall patterns are adequate for the crop each year, the effect of years may not exhibit GEIs (Mercer-Quarshie 1980).

Once GEIs occur, then further analysis could be done to look at the best genotype and environment as well as the stability of the genotypes across the different environments. This could be achieved by employing the GGE biplot procedure. A GGE biplot is a biplot that displays the genotypic main effect (G) and (GE) of a GE dataset which could be visualized. ‘Which-won-where’, one of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment dataset. Many researchers find this use of a biplot intriguing, as it graphically addresses important concepts such as crossover GE, mega-environment differentiation, specific adaptation etc. A polygon is first drawn on genotypes that are furthest from the biplot origin so that all other genotypes are contained within the polygon. Then perpendicular lines to each side of the polygon are drawn, starting from the biplot origin. Genotypes located on the vertices of the polygon performed

either the best or the poorest in one or more environments and the perpendicular lines are equality lines between adjacent genotypes on the polygon which facilitate visual comparison of them. The equality lines divide the biplot into sectors, and the winning genotype for each sector is the one located on the respective vertex and the pattern gives rise to different mega environments (Yan & Tinker 2006). Comparison biplot compares the performance of the environments (or genotypes) with that of an "ideal" environment (or genotype). The specific environment (or genotype) is viewed as an "ideal" environment (or genotype), and concentric circles are plotted around it. The closer an environment (or genotype) is to the "ideal" environment (or genotype) the more attributes they share. The constructed "ideal" environment (or genotype) lies on the line that joins the origin to the (average-environment coordination) *AEC*, at a distance from the origin equal to the distance from the origin to the environment (or genotype) with the greatest yield. (The "ideal" environment or genotype considers only those environments or genotypes that show greater than average yield.) The "ideal" environment (or genotype) is represented by an arrow on the plot. In practice the "ideal" is unlikely to exist, but can be used as a reference point (Yan & Kang 2003). Ranking also shows the best performing environments (or genotypes) in a genotype (or environment) in a single dimension. This draws a biplot axis through the specific environment (or genotype) together with ranking lines to show the best performing genotypes (or environments) in that environment (or genotype). The ranking lines are drawn to be perpendicular to the biplot axis. In the plot, the best performing genotypes (or environments) are those whose projections onto the biplot axis are closest to the environment (or genotype) (Yan & Kang 2003).

The use of genotype main effect (G) plus (GE) interaction (G+GE) biplot analysis by plant breeders and other agricultural researchers has increased dramatically during the past 5 years for analyzing multi-environment trial (MET) data (Gabriel 1971; Yan et al. 2000; Yan & Tinker 2006; Yan et al. 2007). Several crops have been used including Maize (Shiri 2013), wheat and barley (Farshadfar et al. 2012; Mohamed et al. 2013), Yam (Otoo & Asiedu 2008), lemon grass (Bhan et al. 2005), Soya bean (Sousa et al. 2015), Okra (Olayiwola & Ariyo 2013), Sunflower (Pourdad & Moghaddam 2013), Chickpea (Maqbool et al. 2015), Pigeon pea (Srivastava et al. 2012), rice (Stanley et al. 2005; Tabien et al. 2008), common beans (Asfaw & Blair 2014) and *P. radiata* (Ding et al. 2007).

Several results from GGE biplot analysis have been reported. Dehghani et al. (2009) evaluated the stability of grain yield of 11 late maize hybrids with a check cultivar for 2 years at 11 sites in multi-environment trials in Iran. Biplot analysis indicated that the first 2 principal components (PC1 and PC2) explained 44% and 27% of GGE sum of squares (SS), respectively. One variety was detected to be most stable and

was recommended for commercial release in Iran. An ideal environment was also determined and 5 winning genotypes and 3 mega-environments were identified. Drought stress is one of the most important environmental constraints contributing to grain yield instability of maize. Shiri (2013) evaluated maize genotypes under different stresses for identifying genotypes that combine stability with high yield potential for stress-prone areas. GGE biplot explained 94.7% of the total grain yield variation. An ideal genotype with higher grain yield and yield stability and better adapted to all the test environments was identified. Kptor et al. (2014) also studied grain yield for 13 maize genotypes at Kwadaso and Ejura in the forest and forest-transition zones of Ghana respectively under six environments. GGE biplot analysis revealed that PC1 and PC2 for model 3 explained 99% of yield variation. Kwadaso under 90 kgN/ha was ideal for selecting superior genotypes and best genotypes included Mamaba, Etubi and GH110.

In other crops, Farshadfar et al. (2012) studied the genetic architecture of phenotypic stability and management of adaptational genes for improvement of plant adaptation in barley, wheat-barley disomic addition lines. The GGE biplot analysis showed that PC1 and PC2 accounted for 39.1% and 37.7% of GGE sum of squares, respectively, explaining a total of 76.8% variation. Six vertex genotypes, an ideal genotype and genotypes with high stability were identified in the study. Mohamed et al. (2013) also evaluated grain yield of 10 wheat genotypes at 12 environments and showed that three principal components (PCAs) were significant ($P < 0.01$) and PCA 1, PCA 2, and PCA 3 accounted for 65.49, 17.10 and 10.11% of the GEI, respectively. Three stable genotypes that were highest in yield were detected by the GGE-biplot. Tabien et al. (2008) studied the performance of blight resistant rice genotypes in farmers' field. The GGE biplot analysis identified stable genotypes as well as suitable areas for its commercial production to support their varietal release. Bhan et al. (2005) used six varieties/strains of lemongrass evaluated for oil yield across four years. GGE biplot revealed one genotype to be the highest yielding and 1998-99 and 2000-01 closest to the ideal environment and thus most representative of all environments. Olayiwola & Ariyo (2013) also used GGE biplot analysis in 12 Okra varieties and identified 2 mega environments and a best location. Asfaw & Blair (2014) in their studies with common beans used the comparison biplot to identify the most stable variety as located at the center of the concentric circles where an ideal cultivar should be. The inferior varieties were located at far end of the concentric circles for the ideal cultivar. Otoo & Asiedu (2008) reported yield data of 20 genotypes of *D. rotundata* cultivar "Dente" tested across 15 rain-fed environments in Ghana during the 2000 to 2004 growing season and the GGE biplot method indicated that the PC1 and PC2 explained 63.8 and 12.0% of GGE sum of squares (SS), respectively. Two ideal genotypes, a single mega-environment

and the most representative and discriminating environment, Wenchi (forest-savanna transition) were identified.

As indicated earlier, physico-chemical property determination is part of the requirements for varieties to be released in Ghana. Water binding and swelling capacities of maize varieties are very important considerations for most end users especially those who use corn dough for various purposes. Nutritionally, maize is a good source of carbohydrates and higher contents of protein in new varieties is desirable. The poor quality of protein in maize could be attributed to the lack of two essential amino acids namely lysine and tryptophan that are necessary for the human body to properly metabolize protein and this could lead to malnutrition in the form of protein deficiency, also known as wet malnutrition or kwashiorkor (Geek 2016). The protein in conventional maize may range from 5.2-13.7% of the weight of the kernels depending on the variety of maize (Geek 2016). Since maize is used in making several local dishes, it is important they have the capacity to readily dissolve in water and for this reason, determination of water binding capacity is very important. Water binding capacity is the tendency of water to associate with hydrophilic ('water loving') substances. Water is considered to be the 'universal' solvent. However, only hydrophilic materials will dissolve in water readily. Whenever one dissolves compounds or molecules into water, one is taking advantage of the fact that these chemicals are hydrophilic. If a compound is hydrophilic then this means the compound readily dissolves in water or a watery solvent. Furthermore, water is a polar molecule which implies that it has partial charges due to uneven bonding. Oxygen in a water molecule is highly electronegative, which means that it will pull the electrons in a bond closer to its core. This, in turn, makes oxygen partially negative and hydrogen partially positive. Since water has these partial charges, it can attract other chemicals that also have partial charges. Therefore, hydrophilic molecules must have a charged portion in order to dissolve in water (Yogesh 2014). Proximate composition of sweet corn, pop corn, white corn and yellow corn have been studied by Nwalo (2010) and for the 4 varieties, he reported that moisture content was between 8.0-13% while crude protein was at the range of 7.00 - 8.75%. Ash and crude fat were between 0.5-1.0% and crude fibre was between 2.5-8.0%. Total carbohydrate was between 69-76%. In other studies, Oladeji et al. (2013) determined the physico-chemical properties of flour of yam, cocoyam, breadfruit and plantain and they reported that moisture content was between 4.9-63% while crude protein was at the range of 4.8-5.1%. Ash was 1.5-3.5%, crude fat was between 1.0-1.7% and crude fibre was between 0.2-1.4%. Total carbohydrate was between 79-83%. Swelling capacity was between 2.7-4.0% and water binding capacity was 160-268%.

Consumer preferences are vital for acceptance of new varieties. Generally, panelists or participants would taste and feel products from the new varieties and either accept or reject it for

consumption. For example quality protein maize (QPM) and biofortified orange maize are recent innovations that have been tested in various countries. Meenakshi et al. (2010) conducted a study to determine consumer acceptance of biofortified orange maize in rural Zambia by eliciting consumers' willingness to pay and realized that the negative perception of yellow maize did not affect orange maize which is well liked and that there was a premium for orange maize with nutrition information. Similar results were obtained in Ghana by Hugo et al. (2010). Stevens & Winter-Nelson (2008) also examined the acceptance of pro-vitamin A biofortified maize through taste tests and a trading experiment conducted in Maputo, Mozambique. On average, participants ranked the taste, texture, and appearance of their local white maize over an orange, biofortified variety and over a white variety with similar texture and flavor as the biofortified maize. According to Kiria (2010) consumer characteristics of QPM were highly appreciated for stiff porridge, a major maize product in East Africa and consumers were willing to pay more for QPM than for conventional maize in all evaluation criteria used.

Most farmers would look at the economic benefits of adopting new varieties. The PVA maize varieties have other advantages of solving malnutrition problems. Several interventions are in place to solve vitamin A deficiency problems but all the various interventions involve cost. For example, annually Ghana loses

over US\$177 million in Gross Domestic Product to vitamin and mineral deficiencies and scaling up core micronutrient interventions would cost up to US\$10 million per year (UNICEF & MI 2004; World Bank 2009) and this could translate to US\$0.05-US\$3.60 per person annually given returns of investment of 8-30 times the cost (Horton 2009). An investment is considered profitable if the benefit/cost ratio is higher than 1 (Maredia et al. 2000). Since maize is a major staple in Ghana, a feasible approach to minimize VAD is to develop, release and promote the production and utilization of maize varieties that have high levels of bio-available vitamin A with good agronomic traits as well as high economic benefits. Thus, it became necessary to study the performance of pro-vitamin A maize synthetics and hybrids with the objective of releasing superior varieties to farmers.

2. MATERIALS AND METHODS

2.1. Study sites

The trials were established at Kwadaso, Fumesua (forest zone), Kpeve, Ejura, Akumadan (transition zone), Pokuase (coastal savanna zone) and Nyankpala (Guinea savanna zone). A brief description of the study sites are presented in Table 1.

Table 1. Description of study sites

Site	Ecological zone	Mean Annual rainfall ^{§§§} (mm)	Latitude (N)	Longitude (W)	Altitude [†] (m)	Soil Type [†]
Kwadaso	Deciduous Forest	1500	6° 42'††	1° 39'††	268††	Coarse sandy-loam, Paleustult
Fumesua	Deciduous Forest	1500	6° 41'††	1° 28'††	289 [§]	Coarse sandy-loam, Paleustult
Ejura	Transition	1300	7° 23' [§]	1° 22' [§]	235 ^{##}	Fine coarse sandy-loam, Oxisol
Kpeve	Transition	1300	6° 41'††	0° 20'E††	188††	Fine coarse sandy-loam, Oxisol
Akumadan	Transition	1300	7° 24'††	1° 57'††	389††	Forest Ochrosols†††
Pokuase	Coastal savanna	800	5° 36'†	0° 10'†	78 ^{§§}	Coarse sandy-loam, Dystrochrept
Nyankpala	Guinea Savanna	1100	9° 24'††	0° 58'††	170††	Fine sandy-loam, Alfisol

Source: †Sallah et al. 2004; ††Wikipedia 2016; †††Obeng 2000; §Distances 2016; ##Distanceto; §§Elevationmap 2016; §§§Facts and figures 2012

2.2. Genotypes used

The source germplasm was from International Institute of Tropical Agriculture (IITA). In 2013, the first set of trial consisted of 5 IITA PVA synthetics and 3 orange/yellow maize commercial varieties (Abontem, Honampa and Golden Jubilee). The second trial included 11 IITA PVA hybrids and 3 commercial varieties (Abontem, Odomfo and Golden Jubilee). In 2014 the first set of trial consisted of 5 IITA PVA synthetics and 2 commercial varieties (Abontem and Honampa). The second trial included 7

IITA PVA hybrids and 3 commercial varieties (Abontem, Honampa and Odomfo).

2.3. Design and management of trials

The design of the trials was a Randomized Complete Block with 4 replications. The plot consisted of 2 rows of 5 m length. Inter-row spacing was 0.75 m and intra-row spacing was 0.25 m. Plants were thinned to 1 plant per hill to obtain a plant

population of 53,333 plants/ha. Split application of fertilizer was done at a rate of 90 kg N/ha and 60 kg P₂O₅ and 30 kg K per hectare. Hand weeding was done on all fields when necessary to keep the plots free from weeds. Data was recorded from the 2 rows for days to 50% silking and anthesis; plant and ear heights; root and stalk lodging; field weight; plants harvested; total number of ears harvested; grain moisture (%) at harvest; cob aspect; open tips (husk cover); rotten ears and diseases. Controlled pollinations were used in 3 plants for the carotenoid analysis. The 3 ears each of hybrid/synthetic were harvested and placed in clean polyethylene bags for sun drying to the desired moisture content. These ears were manually shelled and random samples drawn from each entry and transferred to clean small sized seed envelopes and mailed to IITA for carotenoid analysis.

2.4. On-farm testing

The on-farm trial was conducted at Akumadan. The trial was research managed and consisted of Pro-vitamin A rich synthetic maize varieties and hybrids recommended from the Crops Research Institute (CRI) maize breeding on-station evaluations. The on-farm testing involved 2 trials per year given a total of four trials established during the 2 year period. In 2013 the first set of trial consisted of 5 IITA PVA synthetics, 2 orange maize commercial varieties (Abontem and Honampa) and a farmer variety. The second trial included 11 IITA PVA hybrids, 2 commercial varieties (Abontem and Odomfo) and a farmer variety. In 2014 the first set of trial consisted of 5 IITA PVA synthetics, 2 commercial varieties (Abontem and Honampa) and a farmer variety. The second trial included 7 IITA PVA hybrids, 2 commercial varieties (Honampa and Odomfo) and a farmer variety. The plot consisted of 4 rows of 5 m length. Inter-row spacing, plants per hill, plant population and fertilizer application and weeding procedures were same as stated in the main trial above. Farmers around the communities were invited to observe and select their preferred varieties at the vegetative and harvesting stages. Field days were organized for farmers with the objective of selecting and/or ranking varieties/hybrids based on farmers' own criteria (i.e. performance parameters e.g. seed size and texture, vegetative and reproductive growth and durations etc.). Researchers and extension agents also made their own selection.

2.5. Data analysis

Both on station and on-farm data were analyzed using the GenStat software version 12.1 package of entries that occurred in all years. Significant differences and genotype x environment interaction was determined using the analysis of variance procedure. Best genotypes, environment and stability of the genotypes across the different environments was determined using the GGE bi-plot in the above named software. Grain yield was expressed in kg/ha at 15 % moisture using the formula:

Grain yield = (Field weight (kg)/harvested area (m²) × (10,000m² /ha) × (100 – % grain moisture)/85 × 0.8 (shelling %).

2.6. Determination of morphological characters

Cob length, cob diameter and kernel depth were measured using calipers and the average of 5 cobs was taken for each trait. Cob length was measured from the base of the cob to the tip. Cob diameter was measured mid-way of the unshelled cob. Kernel depth was measured from the base of the seed to the tip. Kernel arrangement, kernel type, tassel colour, tassel arrangement, silk and stem colour were all described according to standard protocols of the variety release procedures.

2.7. Determination of Physico-chemical properties

The contents of moisture, protein, fibre, fat, ash, carbohydrate as well as water binding capacity, solubility and swelling power of the genotypes were determined according to standard laboratory procedures.

2.8. Determination of consumer preferences

Two approaches were used. The first approach involved a preliminary survey of the extent to which farmers and other end users have accepted the yellow/orange maize in 7 locations in the forest and forest-transition zones of Ghana. A total of 400 respondents were used in answering a close-ended questionnaire. The second approach was a sensory evaluation involving 40 respondents who were invited to determine their likeness of the new genotypes for 2 local dishes namely Banku and Ga Kenkey. These were made up of scientists, technicians, students, farmers, kenkey sellers and other end users.

2.9. Economic analysis procedure

The grain yield from on-farm was used. Cost benefit ratio was estimated to get the idea whether improved maize production would be beneficial or not to producers. It was estimated using the following formula:

$$C - B \quad \text{ratio} = \frac{GI}{TC}$$

Where GI is the Gross Income per hectare of maize and TC represents the Total Cost of production for one hectare of maize. The difference between the gains and the costs of generation is explained by the Benefit cost ratio (Gittinger 1982).

3. RESULTS AND DISCUSSIONS

3.1 Genotype and Genotype x Environment interaction.

The mean squares of combined analysis of grain yield, days to mid-silk, plant height and cob aspect scores of 4 PVA synthetics and 2 commercial checks for 13 environments is presented in Table 2. There was highly significant ($p < 0.01$) GEI observed for grain yield and days to mid-silk. Again, there was highly significant difference ($P < 0.01$) amongst the varieties for grain yield (Table 3). Yields from across locations ranged from 1.7-2.5 t/ha. The highest yield of 2.5 t/ha was obtained in PVA SYN 13 and this was 23% higher than the commercial check Honampa. Yields from Akumadan and Pokuase in 2013 were very low due to the effect of drought stress during the growing period. Results of days to mid-silk across 13 environments are

presented in Table 4. Most of the varieties flowered between 54 and 58 days after planting and these differences were highly significant ($P < 0.01$). Results of plant height across 13 environments are presented in Table 5. Plant height ranged from 160 cm in Honampa to 168 cm in PVA SYN 13 though differences were not significant. Results of cob aspect across 13 environments are presented in Table 6. Most of the varieties had cob aspect scores of 2.6-3.1 and these differences were highly significant ($P < 0.01$). The best cob aspect of 2.6 was in PVA SYN 13. Disease scores were generally between 1 and 3 (not presented) indicating tolerance to streak, rust and blight.

Table 2. Mean squares of combined analysis for grain yield, days to mid-silk, plant height and cob aspect of 4 Pro-vitamin A synthetic maize genotypes and 2 commercial checks studied in 13 environments in 2013 and 2014

Source of Variation	DF	Grain Yield (kg/ha)	Days to mid-silk	Plant height (cm)	Cob Aspect (score)
Reps.	3	388030	16.4	1586.5	0.2853
Genotypes (G)	5	5055554**	103.8**	457.7NS	1.8571**
Environment (E)	12	14989917**	160.6**	9347.0**	8.3152**
GE	60	667102**	6.211**	239.9NS	0.3543NS
Residual	231	407479	3.012	241	0.2723
Total	311				

**Highly significant at $P < 0.01$ and NS=Non-significant

Table 3. Grain yield kg/ha of 4 Pro-vitamin A synthetic maize varieties and 2 commercial checks evaluated in 13 environments in 2013 and 2014

Location Variety	.....2013.....						.....2014.....						Across	
	1	2	3	4	5	6	7	8	9	10	11	12		13
PVA SYN 13	1461	1373	1020	869	3345	3177	3252	1962	3046	3152	2711	4117	3564	2542
PVA SYN 14	1326	943	560	622	2125	2765	1903	1675	2163	2380	2320	2039	1805	1741
PVA SYN 9	1287	993	876	992	1452	3630	1542	1814	1876	2345	1620	2646	1046	1701
PVA SYN 16	1273	1064	724	876	2253	3137	1963	1646	2031	2973	1318	2295	2296	1835
Abontem	1336	712	1423	1056	2616	3104	2185	1441	2573	1978	2125	3960	2399	2070
Honampa	1407	1179	696	734	2276	3353	1939	1479	2335	2665	2170	4054	2534	2063
Mean	1348	1044	883	858	2344	3194	2131	1669	2337	2582	2044	3185	2274	1992
SED	NS	NS	NS	NS	377**	NS	320**	NS	323*	272**	NS	358**	430**	125**
CV%	9.8	33.0	42.2	45.2	22.7	16.0	21.3	18.9	19.6	14.9	39.9	15.9	26.7	32.0

1= Fumesua A; 2= Akumadan A; 3= Pokuase A; 4= Kpeve A; 5= Akumadan B; 6= Nyankpala A; 7= Fumesua A; 8= Akumadan A; 9= Pokuase A; 10= Kwadaso A; 11= Ejura A; 12= Kwadaso B; 13= Nyankpala A; A=Major season; B=Minor season; **, *Highly significant at $P < 0.01$ and $P < 0.05$ respectively; NS=Non-significant

Table 4. Days to mid-silk of 4 Pro-vitamin A synthetic maize varieties and 2 commercial checks evaluated in 13 environments in 2013 and 2014

	.....2013.....					.....2014.....								
Location	1	2	3	4	5	6	7	8	9	10	11	12	13	Across
Variety														
PVA SYN 13	52	61	55	57	58	58	59	55	56	53	57	59	61	57
PVA SYN 14	55	62	58	59	58	56	60	55	56	54	56	60	61	58
PVA SYN 9	52	63	55	57	59	55	61	56	57	53	59	58	61	57
PVA SYN 16	52	61	55	59	57	55	59	55	57	52	58	59	61	57
Abontem	52	56	52	51	55	52	56	54	53	52	49	57	59	54
Honampa	53	59	56	58	58	55	58	55	56	53	56	58	61	57
Mean	52	60	55	57	57	55	59	55	56	53	56	59	60	56
SED	0.6**	0.7**	0.7**	2.1*	NS	1.0**	1.2**	NS	0.7**	0.5*	1.5**	NS	0.7*	0.3**
CV%	1.6	1.6	1.8	5.3	2.9	2.6	2.8	2.1	1.7	1.2	3.8	3.2	1.7	3.1

1= Fumesua A;2= Akumadan A;3=Pokuase A;4= Kpeve A;5= Akumadan B;6= Nyankpala A;7= Fumesua A; 8=Akumadan A;9= Pokuase A;10= Kwadaso A; 11= Ejura A;12= KwadasoB;13= Nyankpala A; A=Major season; B=Minor season; **, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 5. Plant height (cm) of 4 Pro-vitamin A synthetic maize varieties and 2 commercial checks evaluated in 13 environments in 2013 and 2014

	.....2013.....					.....2014.....								
Location	1	2	3	4	5	6	7	8	9	10	11	12	13	Across
Variety														
PVA SYN 13	130	121	163	188	177	169	183	158	187	208	169	164	169	168
PVA SYN 14	130	133	156	170	176	170	183	166	182	190	176	157	147	164
PVA SYN 9	118	123	159	185	180	184	159	152	173	187	169	154	159	162
PVA SYN 16	123	134	159	168	182	191	187	167	191	201	156	158	149	166
Abontem	125	127	159	165	178	150	175	175	184	197	172	161	160	164
Honampa	128	128	164	163	169	173	163	160	175	188	165	153	153	160
Mean	126	128	160	173	177	173	175	163	182	195	168	158	157	164
SED	NS	NS	NS	NS	NS	10*	8*	NS	NS	5**	NS	NS	NS	NS
CV%	8.9	8.9	4.7	11.3	3.5	8.5	6.4	7.7	4.7	3.3	9.0	5.3	7.6	9.5

1= Fumesua A;2= Akumadan A;3=Pokuase A;4= Kpeve A;5= Akumadan B;6= Nyankpala A;7= Fumesua A; 8=Akumadan A;9= Pokuase A;10= Kwadaso A; 11= Ejura A;12= KwadasoB;13= Nyankpala A; A=Major season; B=Minor season; **, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 6. Cob Aspect (score) of 4 Pro-vitamin A synthetic maize varieties and 2 commercial checks evaluated in 13 environments in 2013 and 2014

Location	.....2013.....					.....2014.....								Across
	1	2	3	4	5	6	7	8	9	10	11	12	13	
Variety														
PVA SYN 13	3.0	2.5	3.0	3.5	2.0	1.2	2.5	3.5	2.2	2.5	3.2	3.0	1.8	2.6
PVA SYN 14	3.8	3.2	3.5	4.0	3.0	2.0	3.2	3.8	2.5	2.8	3.0	3.2	2.5	3.1
PVA SYN 9	4.0	2.8	3.2	3.5	3.0	1.0	3.0	3.8	2.0	3.0	3.0	3.0	2.5	2.9
PVA SYN 16	3.0	3.2	3.2	3.8	2.2	1.8	3.2	4.0	3.0	2.8	3.5	3.0	3.0	3.1
Abontem	3.2	3.0	3.2	3.2	2.2	2.0	2.8	3.8	2.2	3.2	3.0	3.5	2.0	2.9
Honampa	4.0	3.2	2.8	4.0	3.0	2.0	3.0	4.0	2.8	2.8	3.5	3.2	2.0	3.1
Mean	3.5	3.0	3.2	3.7	2.6	1.7	3.0	3.8	2.5	2.8	3.2	3.2	2.3	2.9
SED	0.2**	NS	NS	NS	0.2**	0.3**	NS	NS	0.3*	NS	NS	NS	0.4*	0.1**
CV%	9.0	17.9	14.9	16.5	11.5	22.8	14.6	12.0	15.3	17.4	12.2	12.0	22.4	17.1

1= Fumesua A;2= Akumadan A;3=Pokuase A;4= Kpeve A;5= Akumadan B;6= Nyankpala A;7= Fumesua A; 8=Akumadan A;9= Pokuase A;10= Kwadaso A; 11= Ejura A;12= KwadasoB;13= Nyankpala A; A=Major season; B=Minor season; score#: 1=clean uniform well filled ears and 5=rotten, variable and partially filled cobs
 **, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

The mean squares of combined analysis of grain yield, days to mid-silk, plant height and cob aspect scores of 7 PVA hybrids and 2 commercial checks for 12 environments is presented in Table 7. There was highly significant (p<0.01) GEI observed in all traits mentioned above with the exception of plant height which was not significant. Again, there was highly significant difference (P<0.01) amongst the varieties for grain yield (Table 8). Yields from across locations ranged from 1.8-3.5 t/ha. The highest yield of 3.5 t/ha was obtained in LY0905-35 and this was 87% higher than the commercial check Odomfo. Yields from Pokuase and Kpeve in 2013 were very low due to the effect of drought stress during the growing period. Results of days to mid-silk across 12 environments are presented in Table 9. The varieties flowered between 54 and 60 days after planting and these differences were highly significant (P<0.01). The earliest variety was Abontem. Results of plant height across 12 environments are presented in Table 10. Plant height ranged from 161 cm in Odomfo to 190 cm in L1001-3 and these differences were highly significant (P<0.01). Results of cob aspect across 12 environments are presented in Table 11. The varieties had cob aspect scores between 2.3 and 3.0 and these differences were highly significant (P<0.01). Disease scores were generally between 1 and 3 (not presented) indicating tolerance to streak, rust and blight. Results of Pro-vitamin A

contents of PVA maize hybrids and synthetics evaluated in IITA regional trials across 5 locations in 2013 and 2014 are presented in Tables 12 and 13. The entries that were amongst the top eight and three genotypes of high PVA contents of the hybrids and synthetics respectively are reported. LY1001-14 had up to 9.2 µg/g in 2012 and LY1001-10 had up to 11.3 µg/g in the same year while PVA SYN-13 had up to 9.3 µg/g. GEI observed in the two trials were possible because the trial environments were different and may suggest location specific variety development (Allard & Bradshaw 1963; Akposoe (1971); Akposoe (1975); Badu-Apraku et al. 2003; Sallah et al. 2004; Kpotor et al. 2014) However, Badu-Apraku et al. 2003 and Sallah et al. 2004 did their evaluations in 30 and 36 environments respectively as opposed to 12-13 environments in this study while Kpotor et al. 2014 used as low as 6 environments. In the 2 trials, the varieties had cob aspect scores between 2.0 and 3.0 and this implied non rotten and somehow uniform cobs. The disease scores of between 1 and 3 obtained in the 2 trials indicated tolerance to streak, rust and blight. This was so because the source germplasm was from IITA and these genotypes were selected against these diseases by breeders there.

Table 7. Mean squares of combined analysis for grain yield, days to mid-silk, plant height and cob aspect of 7 PVA hybrid maize varieties and 2 commercial checks studied in 12 environments in 2013 and 2014

Source of Variation	DF	Grain Yield (kg/ha)	Days to mid-silk	Plant height (cm)	Cob Aspect (score)
Reps.	3	649173	3.81	181.9	0.0926
Genotypes (G)	8	19735451**	97.8**	4358.5**	3.3385**
Environment (E)	11	46433241**	297.3**	15125.2**	7.7121**
GE	88	1319092**	7.98**	293.5NS	0.3632**
Residual	321	472863	3.14	289.5	0.2063
Total	431				

**Highly significant at P<0.01 and NS=Non-significant

Table 8. Grain yield kg/ha of 7 PVA hybrid maize varieties and 2 commercial checks evaluated in 12 environments in 2013 and 2014

Location	.....2013.....				.....2014.....								Across
	1	2	3	4	5	6	7	8	9	10	11	12	
Variety													
Odomfo	1854	780	960	3102	2438	1365	1513	2049	1524	1767	4163	1121	1886
LY 905-35	2477	753	2062	3444	3591	3869	2592	4922	4138	2465	6729	5203	3520
LY 905-34	2235	670	2229	3435	3720	4234	3498	5050	3570	2624	5942	3897	3425
L1001-3	1525	651	888	2528	2436	1824	2304	3811	2096	2044	4425	3622	2346
LY 1001-14	2031	936	1502	3567	3771	3483	2308	4315	3412	2012	5581	3822	3061
LY 1001-10	1590	700	945	2942	2276	3942	3296	4792	4034	3155	6129	3923	3144
LY-1001-22	1853	1045	1644	3922	3186	3292	2424	4135	3314	2838	5385	3358	3033
LY 1001-21	2010	1350	1587	3321	2708	3559	3679	4837	3219	3593	4541	5932	3195
Abontem	1318	1095	1015	2549	2834	1332	1295	1856	2320	1243	3528	1529	1826
Mean	1877	887	1426	3201	2995	2989	2545	3974	3070	2416	5158	3379	2826
SED	325*	NS	452*	NS	481*	408**	411**	399**	364**	629*	525**	405**	140**
CV%	24.5	57.5	44.8	22.3	22.7	19.3	22.8	14.2	16.8	36.8	14.4	16.9	24.3

1= Fumesua A;2= Pokuase A;3=Kpeve A;4= Akumadan B;5= Nyankpala A;6= Fumesua A;7= Akumadan A;8= Pokuase A;9= Kwadaso A;10= Ejura A; 11=Kwadaso B;12= Nyankpala A; A=Major season; B=Minor season

**, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 9. Days to mid-silk of 7 PVA hybrid maize varieties and 2 commercial checks evaluated in 12 environments in 2013 and 2014

Location Variety	.....2013.....				.....2014.....								Across
	1	2	3	4	5	6	7	8	9	10	11	12	
Ɔdomfo	53	59	60	55	59	60	54	58	54	62	57	63	58
LY 905-35	54	61	60	59	61	61	56	58	55	66	57	62	59
LY 905-34	54	59	57	57	60	60	54	58	54	63	57	63	58
L1001-3	51	55	58	57	61	60	54	58	53	60	56	62	60
LY 1001-14	56	60	58	58	62	61	55	57	54	64	56	62	58
LY 1001-10	55	61	60	56	61	60	54	56	52	62	55	62	58
LY-1001-22	53	60	56	58	61	59	54	57	54	62	56	62	58
LY 1001-21	51	56	59	58	59	60	54	57	53	60	58	61	57
Abontem	52	57	51	54	56	55	52	55	52	51	55	59	54
Mean	52	59	57	57	60	59	54	57	53	61	56	62	57
SED	0.9**	1.1**	1.8**	1.5*	1.4*	0.7**	NS	0.6**	0.8*	1.8**	NS	0.8**	0.4**
CV%	2.3	2.6	4.3	3.8	3.2	1.6	2.3	1.4	2.2	4.1	3.8	1.8	3.1

1= Fumesua A;2= Pokuase A;3=Kpeve A;4= Akumadan B;5= Nyankpala A;6= Fumesua A;7= Akumadan A;8= Pokuase A;9= Kwadaso A;10= Ejura A; 11=Kwadaso B;12= Nyankpala A

**, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 10. Plant height (cm) of 7 PVA hybrid maize varieties and 2 commercial checks evaluated in 12 environments in 2013 and 2014

Location Variety	.....2013.....				.....2014.....								Across
	1	2	3	4	5	6	7	8	9	10	11	12	
Ɔdomfo	136	157	149	173	149	171	162	188	189	145	164	154	161
LY 905-35	140	160	168	181	174	201	205	216	230	169	177	184	184
LY 905-34	146	147	187	180	176	206	220	219	233	168	192	191	189
L1001-3	159	175	197	180	182	198	210	211	225	183	173	187	190
LY 1001-14	141	143	186	179	170	188	198	200	213	169	167	180	178
LY 1001-10	145	157	175	181	170	192	192	203	220	161	166	175	178
LY-1001-22	146	166	194	194	188	198	186	213	228	183	164	171	186
LY 1001-21	158	173	199	183	171	197	214	206	232	180	172	186	189
Abontem	130	156	196	176	166	177	166	199	210	161	172	153	172
Mean	144	159	184	181	172	192	195	206	220	169	172	176	181
SED	NS	8**	15*	NS	NS	5**	10**	9*	6.2**	NS	7.0*	7.5**	3.5**
CV%	9.6	6.8	11.4	7.5	11.3	3.9	7.3	5.9	4.0	11.8	5.8	6.0	9.4

1= Fumesua A;2= Pokuase A;3=Kpeve A;4= Akumadan B;5= Nyankpala A;6= Fumesua A;7= Akumadan A; 8=Pokuase A;9= Kwadaso A;10= Ejura A; 11=Kwadaso B;12= Nyankpala A; A=Major season; B=Minor season

**, *Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 11. Cob aspect (score[#]) of 7 PVA hybrid maize varieties and 2 commercial checks evaluated in 12 environments in 2013 and 2014

Location Variety	.....2013.....				.....2014.....								Across
	1	2	3	4	5	6	7	8	9	10	11	12	
Ɔdomfo	3.0	2.8	3.2	2.0	2.0	2.2	3.0	2.8	2.5	3.0	2.8	1.8	2.6
LY 905-35	3.0	3.0	2.8	2.0	1.8	2.0	2.5	1.7	2.0	2.8	2.5	1.5	2.3
LY 905-34	3.0	2.5	3.0	2.0	2.2	2.0	2.8	1.7	2.5	2.5	2.5	1.2	2.3
L1001-3	3.0	2.8	3.5	2.2	2.0	3.2	3.0	2.5	3.0	3.5	3.0	1.8	2.8
LY 1001-14	3.0	2.0	3.0	2.2	1.8	2.5	2.8	1.5	2.0	2.2	2.5	2.0	2.3
LY 1001-10	3.0	3.0	3.8	3.0	2.0	2.5	2.5	2.0	2.5	2.0	2.8	1.0	2.5
LY-1001-22	3.0	2.2	3.0	2.2	2.0	2.2	2.5	1.7	2.5	2.5	2.8	1.0	2.3
LY 1001-21	3.0	2.5	3.2	2.2	2.0	2.2	2.2	1.5	2.2	2.8	2.5	1.8	2.4
Abontem	3.2	2.5	3.5	3.0	2.0	3.2	3.2	3.0	3.0	3.8	3.8	2.2	3.0
Mean	3.0	2.6	3.2	2.3	2.0	2.5	2.7	2.1	2.5	2.8	2.8	1.6	2.5
SED	NS	0.3*	NS	0.2**	NS	0.3**	NS	0.3**	0.3**	0.4**	0.3*	NS	0.1**
CV%	5.5	16.3	17.3	13.4	19.4	18.9	17.5	22.2	14.6	17.7	17.1	37.5	18.2

1= Fumesua A;2= Pokuase A;3=Kpeve A;4= Akumadan B;5= Nyankpala A;6= Fumesua A;7= Akumadan A;8= Pokuase A;9= Kwadaso A;10= Ejura A; 11=Kwadaso B;12= Nyankpala A; A=Major season; B=Minor season; score[#]: 1=clean uniform well filled ears and 5=rotten, variable and partially filled cobs

**,*Highly significant at P<0.01 and P<0.05 respectively; NS=Non-significant

Table 12: Mean pro-vitamin A contents (µg/g) of 5 out of 15-17 PVA hybrids evaluated across 5 locations in 2012 and 2013 compared with a commercial variety

Variety	2012	2013
LY905-35	8.2	7.8
LY1001-14	9.2	6.8
LY1001-10	11.3	7.5
LY1001-21	8.9	7.3
LY1001-22	8.5	6.8
Honampa (check)	7.0	7.0
MEAN	7.5	6.8
SED	0.8**	1.0**
CV%	10	13

**Highly significant at P<0.01

Source: IITA carotenoid analysis 2013 &2013

Table 13: Mean pro-vitamin A contents ($\mu\text{g/g}$) of 2 PVA synthetics out of 14-20 PVA synthetics evaluated across 5 locations in 2012 and 2013 compared with a commercial variety.

Variety	2012	2013
PVA SYN 13	9.3	6.4
PVA SYN 9	6.3	5.5
Honampa (check)	7.0	7.0
MEAN	7.5	6.8
SED	0.8**	1.0**
CV%	10	13

**Highly significant at $P < 0.01$

Source: IITA carotenoid analysis 2012 & 2013

3.2. GGE Biplot

Figure 1 shows a graph of a ‘which won where’ of PVA maize synthetics. The GGE biplot analysis showed that PC1 and PC2 accounted for 69.95% and 16.14% of GGE respectively, explaining a total of 86.09% of the yield variation. Genotypes at the vertex hull are considered to be the best performers in the environments that occur in the same sector. If an ellipse extends to another sector the ellipse lines become dashed. A genotype at an apex (G1, G5, G3, G2 and G4) is the winning genotype or the best performing genotype in all the environments that fall within that sector. Genotype G1 (PVA SYN 13) won in environments E1, E2, E5, E7, E8, E9, E10, E11 and E13. Genotype G5 (Abontem) won in environments E3, E4, E6 and E12. In the case of G2, G3 and G4 no environment fell within its sector indicating that they did not have any specific preferences for any particular environment. Two mega-environments were identified. Mega environment 1 is made up of the 9 environments in the oval (E1, E2, E5, E7, E8, E9, E10, E11 and E13). Mega environment 2 is made up of the 4 environments in the oval (E3, E4, E6 and E12).

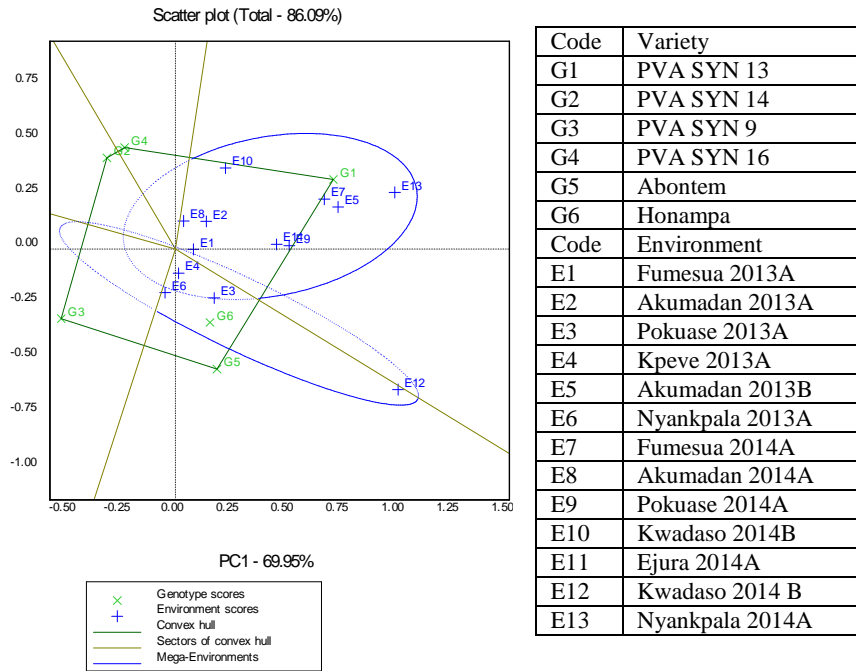
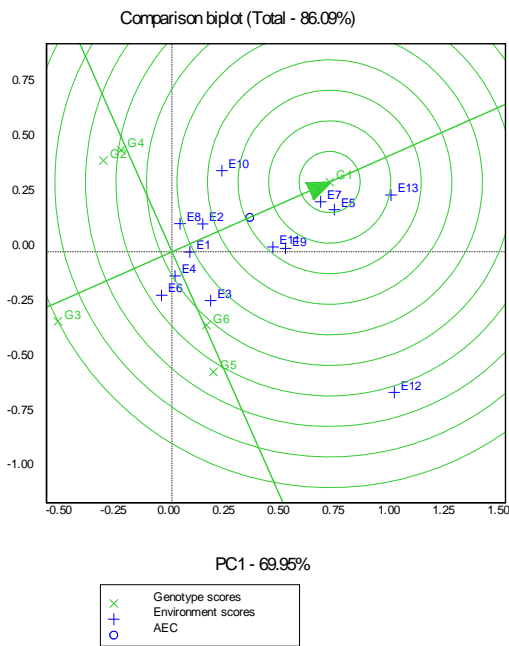


Fig.1. GGE biplot of PVA maize synthetic showing which genotype won in which environment Transformation = 0; Scaling = 0; Drawn to scale

Comparison biplot compares the performance of the environments (or genotypes) with that of an "ideal" environment (or genotype). The specific environment (or genotype) is viewed as an "ideal" environment (or genotype), and concentric circles are plotted around it. The closer an environment (or genotype) is to the "ideal" environment (or genotype) the more attributes they share. The "ideal" environment (or genotype) is represented by an arrow on the plot. In practice the "ideal" is unlikely to exist, but can be used as a reference point. The GGE comparison biplot of PVA synthetic maize varieties based on both mean grain yield and stability performance identified PVA SYN 13 (G1) as superior

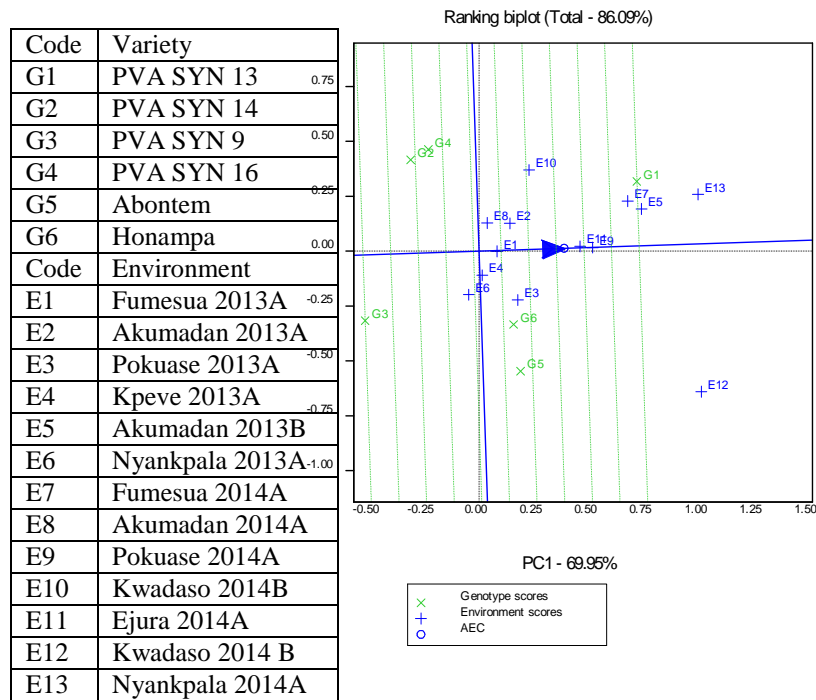
and stable variety (Figure 2) as this was located at the center of the concentric circles where an ideal cultivar should be and the potential yield of this variety was 4 tons/ha at Kwadaso in the minor season of 2014 (Table 3). The genotypes G2 (PVA SYN 14), G3 (PVA SYN 9) and G4 (PVA SYN 16) were inferior in both mean grain yield and stability performance as these were located at far end of the concentric circles for the ideal genotype in figure 2.



Code	Variety
G1	PVA SYN 13
G2	PVA SYN 14
G3	PVA SYN 9
G4	PVA SYN 16
G5	Abontem
G6	Honampa
Code	Environment
E1	Fumesua 2013A
E2	Akumadan 2013A
E3	Pokuase 2013A
E4	Kpeve 2013A
E5	Akumadan 2013B
E6	Nyankpala 2013A
E7	Fumesua 2014A
E8	Akumadan 2014A
E9	Pokuase 2014A
E10	Kwadaso 2014B
E11	Ejura 2014A
E12	Kwadaso 2014 B
E13	Nyankpala 2014A

Fig. 2. GGE comparison biplot of PVA synthetic maize varieties based on both mean grain yield and stability performance Transformation = 0; Scaling = 0; Drawn to scale

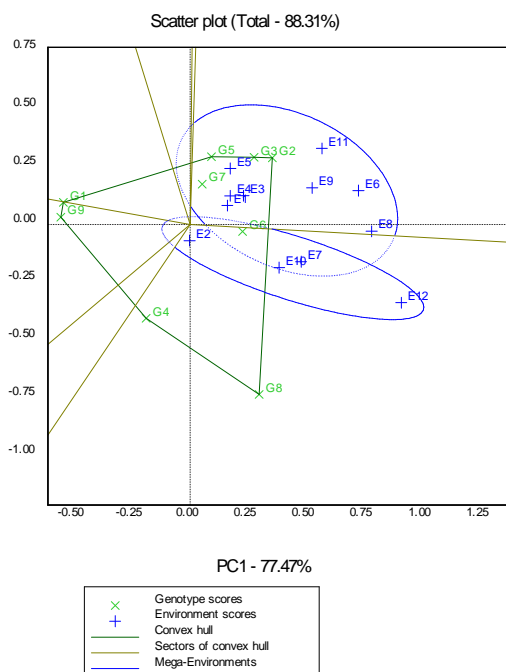
Figure 3 shows graph of ranking biplot. Ranking shows the best performing environments (or genotypes) in a genotype (or environment) in a single dimension. This draws a biplot axis through the specific environment (or genotype) together with ranking lines to show the best performing genotypes (or environments) in that environment (or genotype). The ranking lines are drawn to be perpendicular to the biplot axis. In the plot, the best performing genotypes (or environments) are those whose projections onto the biplot axis are closest to the environment or genotype). Ranking best genotype was G1 (PVA SYN 13) and the best environment was E13 (Nyankpala 2014 A).



Code	Variety	
G1	PVA SYN 13	0.75
G2	PVA SYN 14	
G3	PVA SYN 9	0.50
G4	PVA SYN 16	
G5	Abontem	0.25
G6	Honampa	0.00
Code	Environment	
E1	Fumesua 2013A	-0.25
E2	Akumadan 2013A	
E3	Pokuase 2013A	-0.50
E4	Kpeve 2013A	-0.75
E5	Akumadan 2013B	
E6	Nyankpala 2013A	-1.00
E7	Fumesua 2014A	
E8	Akumadan 2014A	
E9	Pokuase 2014A	
E10	Kwadaso 2014B	
E11	Ejura 2014A	
E12	Kwadaso 2014 B	
E13	Nyankpala 2014A	

Fig. 3. GGE ranking biplot of PVA synthetic maize varieties showing the best performing environments (or genotypes) in a genotype (or environment) in a single dimension. Transformation = 0; Scaling = 0; Drawn to scale

Figure 4 shows a graph of a ‘which won where’ of PVA maize hybrids. The GGE biplot analysis showed that PC1 and PC2 accounted for 77.47% and 10.84% of GGE respectively, explaining a total of 88.31% of the yield variation. Genotype G2 (LY 905-35) won in environments E1, E3, E4, E5, E6, E8, E9 and E11. Genotype G8 (LY 1001-21) won in environments E2, E7, E10 and E12. In the case of G1, G4 and G9 no environment fell within its sector indicating that they did not have any specific preferences for any particular environment. Two mega-environments were identified. Mega environment 1 is made up of the 8 environments in the oval (E1, E3, E4, E5, E6, E8, E9 and E11). Mega environment 2 is made up of the 4 environments in the oval (E2, E7, E10 and E12).

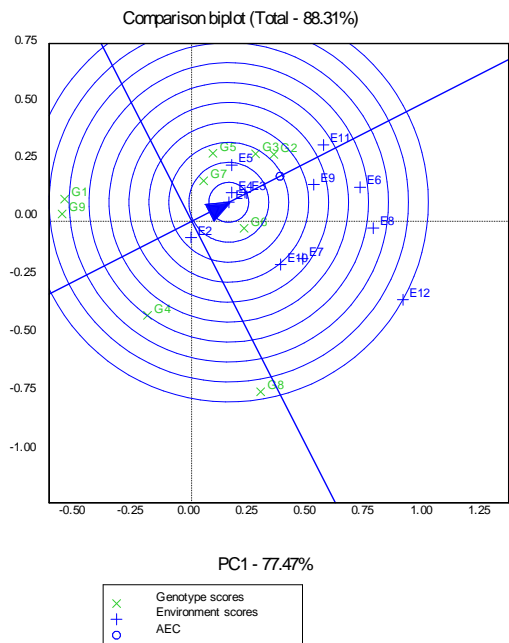


Code	Variety
G1	Ɔdomfo
G2	LY 905-35
G3	LY 905-34
G4	L1001-3
G5	LY 1001-14
G6	LY 1001-10
G7	LY-1001-22
G8	LY 1001-21
G9	Abontem
Code	Environment
E1	Fumesua 2013A
E2	Pokuase 2013A
E3	Kpeve 2013A
E4	Akumadan 2013B
E5	Nyankpala 2013A
E6	Fumesua 2014A
E7	Akumadan 2014A
E8	Pokuase 2014A
E9	Kwadaso 2014A
E10	Ejura 2014A
E11	Kwadaso 2014B
E12	Nyankpala 2014A
A=Major season	B=Minor season

Fig.4. GGE biplot of PVA maize hybrids showing which genotype won in which environment. Transformation = 0; Scaling = 0; Drawn to scale

The GGE comparison biplot of varieties based on both mean grain yield and stability performance identified G5 (LY1001-14), G6 (LY 1001-10) and G7 (LY 1001-22) as superior and stable varieties with G7 as the most stable (Figure 5) as these were located near the center of the concentric circles where an ideal cultivar should be. The potential yields of these genotypes

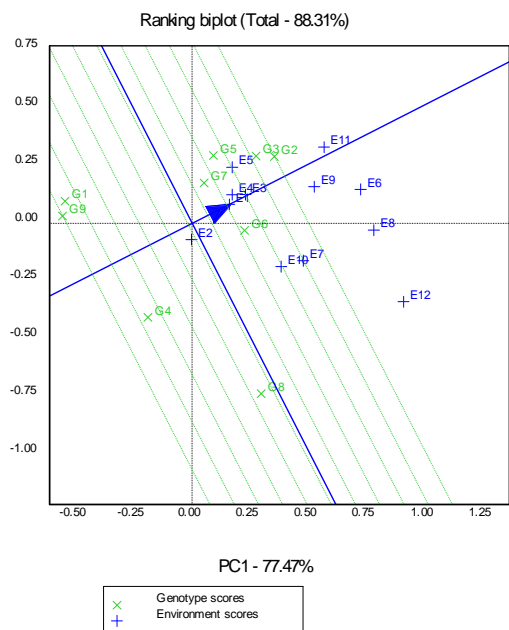
were 6 t/ha, 6 t/ha and 5.4 t/ha respectively at Kwadaso in the minor season of 2014 (Table 8). The genotypes G1 (Ɔdomfo), G4 (LY1001-3), G8 (LY 1001-21) were inferior in both mean grain yield and stability performance as these were located at far end of the concentric circles for the ideal genotype in figure 5.



Code	Variety
G1	Ɔdomfo
G2	LY 905-35
G3	LY 905-34
G4	L1001-3
G5	LY 1001-14
G6	LY 1001-10
G7	LY-1001-22
G8	LY 1001-21
G9	Abontem
Code	Environment
E1	Fumesua 2013A
E2	Pokuase 2013A
E3	Kpeve 2013A
E4	Akumadan 2013B
E5	Nyankpala 2013A
E6	Fumesua 2014A
E7	Akumadan 2014A
E8	Pokuase 2014A
E9	Kwadaso 2014A
E10	Ejura 2014A
E11	Kwadaso 2014B
E12	Nyankpala 2014A
A=Major season	B=Minor season

Fig. 5. GGE comparison biplot of PVA Hybrid maize varieties based on both mean grain yield and stability performance; Transformation = 0; Scaling = 0; Drawn toScale

Figure 6 shows graph of ranking biplot. Ranking best genotype was G2 (LY 905-35) and the best environment was E11 (Kwadaso 2014 B).



Code	Variety
G1	Ɔdomfo
G2	LY 905-35
G3	LY 905-34
G4	L1001-3
G5	LY 1001-14
G6	LY 1001-10
G7	LY-1001-22
G8	LY 1001-21
G9	Abontem
Code	Environment
E1	Fumesua 2013A
E2	Pokuase 2013A
E3	Kpeve 2013A
E4	Akumadan 2013B
E5	Nyankpala 2013A
E6	Fumesua 2014A
E7	Akumadan 2014A
E8	Pokuase 2014A
E9	Kwadaso 2014A
E10	Ejura 2014A
E11	Kwadaso 2014B
E12	Nyankpala 2014A
A=Major season	B=Minor season

Fig. 6. GGE ranking biplot of PVA synthetic maize varieties showing the best performing environments (or genotypes) in a genotype(or environment) in a single dimension. Transformation = 0; Scaling = 0; Drawn to scale

Total PC1 and PC2 values of between 88.3% and 86.09% in both trials were higher than the 71%, 75.8 and 76.8% reported by Dehghani et al. (2009); Otoo & Asiedu (2008); Farshadfar et al. (2012). However, the 94.7% and 99% obtained by Shiri (2013) and Kpotor et al. (2014) were far higher than what was obtained in this study. Differences may be due to different genotypes and environments studied. The 5-6 winning genotypes were similar to that obtained by Dehghani et al. (2009) but higher than that obtained by Olayiwola & Ariyo (2013) and Otoo & Asiedu (2008). Stable genotypes detected by the biplot was in agreement with what other scientists discovered and some used in recommending varieties for release or studying released varieties (Bhan et al. 2005; Tabien et al. 2008; Otoo & Asiedu 2008; Farshadfar et al. 2012; Mohamed et al. 2013; Shiri 2013 Kpotor et al. 2014; Asfaw & Blair 2014. The inferior varieties in our study were located at far end of the concentric circles for the ideal cultivar just as was

observed by Asfaw & Blair (2014). Interestingly, in our study, Kwadaso was the ideal environment for the PVA hybrids just as it was detected by Kpotor et al. 2014. In contrast Otoo & Asiedu (2008) detected Wenchi in the forest-savanna transition zone as the ideal environment from their Yam studies. On-farm results of grain yield of Pro-vitamin A synthetics (OPV) evaluated at Akumadan in 2013 and 2014 are presented in Tables 14 and 15. Again, entries that were amongst the top eight and three genotypes of high PVA contents of the hybrids and synthetics respectively are reported. In both years, the hybrid LY1001-14 had a yield of 2.5-4.0 tons/ha. Similarly, the hybrid LY1001-10 had 3-5 tons/ha. The synthetic PVA-13 over the 2 years yielded 2.5-3.0 tons/ha. All these new varieties in most cases out-yielded the farmer variety by at least 20%.

Table 14: Grain yield (kg/ha) of 5 out of 10-14 PVA Hybrid maize varieties and a local variety evaluated on-farm at Akumadan in 2013 and 2014.

Year	Grain Yield (kg/ha)	
	2013	2014
Variety		
LY905-35	3616	3207
LY1001-14	3671	2454
LY1001-10	2867	4477
LY1001-21	4094	3219
Odomfo	3066	2596
Farmer variety	2300	1886
MEAN	3109	2890
SED	379**	428**
CV%	14.9	20.9

**Significant at 0.01

Table 15: Grain yield (kg/ha) of 2 out of 7 PVA Synthetic maize varieties and a local variety evaluated On-farm at Akumadan in 2013 and 2014

Year	Grain Yield (kg/ha)	
	2013	2014
Variety		
PVA SYN 13	2847	2459
PVA SYN 9	1348	1767
Farmer variety	2365	1696
MEAN	2320	2003
SED	NS	339**
CV%	24.9	24

**Significant at 0.01; NS= Non Significant

3.3. Morphological characteristics

Table 16 indicates some of the morphological characteristics of 3 PVA maize varieties for release. Mean cob length ranged from 14 cm to 17 cm and cob diameter was 4 cm whilst kernel

depth ranged from 0.7 cm to 0.9 cm. All the varieties had straight kernel arrangement and were orange/flint but LY 1001-14 showed deep orange. Tassel colour, tassel arrangement, silk colour, stem colour and days to maturity are all described in Table 17.

Table 16: Cob and kernel characteristics of 3 PVA maize varieties for release

Variety	Cob length (cm)	Cob diameter (cm)	Kernel depth (cm)	Kernel arrangement	Kernel colour/type
LY1001-10	14.3	4.1	0.7	Straight	orange/Flint
LY1001-14	16.7	4.3	0.8	Straight	Deep orange/Flint
PVA SYN 13	16.1	4.1	0.9	Straight	orange/Flint

Table 17: Some agronomic characteristics of 3 PVA maize varieties for release

Variety	Tassel colour	Tassel arrangement	Silk colour	Stem colour	Days to Maturity
LY1001-10	Cream	Open and alternate	Cream with light purple base	Green	110-115
LY1001-14	Cream purple	Open and alternate	Cream with deep purple base	Green	110-115
PVA SYN 13	Cream Purple	Open and alternate	Purple	Green	110-115

3.4. Physico-Chemical analysis

Table 18 indicates moisture, protein, fibre, fat, ash, carbohydrate, water binding capacity, solubility and swelling power of 3 maize varieties for release compared with a commercial check. Highly significant ($P < 0.01$) differences were observed among the varieties for all the properties. Mean moisture ranged from 11 to 12%. Protein content ranged from 5.0-13.4%. Fibre content was approximately 2% for all varieties and their fat contents were 4%. Ash content for all the varieties was between 1-3% with Carbohydrate content of between 68-76%. Water binding capacity for all the varieties were between 55-75%. Solubility values for all the varieties ranged from 13-21% with swelling power between 7-10%. The protein content of between 5.0-13.4% observed in the PVA maize varieties

studied was similar to the 5.2-13.7% reported by (Geek 2016) and the lower value of 5 was also similar to that obtained by Oladeji et al. (2013). Moisture content reported from our study was slightly lower than that obtained by Nwalo, 2010 . Ash and crude fat were about twice what was obtained by Nwalo, 2010 and total carbohydrate was similar to that obtained by Nwalo (2010). Oladeji et al. (2013). Ash content obtained in our study was similar to Oladeji et al. (2013) while fat, fibre and swelling power were about twice what was obtained by Oladeji et al. (2013) and WBC obtained in our study was about a third of that obtained by Oladeji et al. (2013).

Table 18. Physico-chemical properties of 3 PVA maize varieties for release in 2015 compared with a commercial variety

Variety	Moisture	Protein	Fibre	Fat	Ash	CHO	WBC	Solubility	SP
LY1001-10	11.7	13.4	1.8	3.7	1.3	68.2	75.4	16.7	8.3
LY1001-14	11.1	12.1	2.2	3.8	1.3	69.6	74.9	18.3	9.9
HONAMPA	11.5	10.3	1.8	3.6	2.8	70.0	73.6	13.0	8.7
PVA SYN 13	11.2	5.0	2.5	3.4	2.3	75.6	55.0	21.0	6.6
Mean	10.9	10.9	2.0	3.7	1.5	70.9	73.2	16.5	8.6
SED	0.3**	0.7**	0.3**	0.2**	0.1**	0.6**	3.5**	0.8**	0.5**
CV%	2.8	3.6	17.0	5.6	10.0	1.1	5.9	5.8	7.2

** Significant at $P < 0.01$; CHO=Carbohydrate; WBC=Water Binding Capacity; SP=Swelling Power

3.5. Consumer Preferences

Table 19 shows results of preliminary survey of acceptability of yellow/orange maize in 7 locations in the forest and forest-transition zones of Ghana. A total of 400 respondents were used. However, 21 of them had not tasted so they were excluded from the analysis. This implied that a total of 379 respondents had ever tasted or used the yellow/orange maize. Out of the 379 respondents, 292 strongly liked it, 78 liked it and 9 moderately liked it representing 77%, 20.6% and 2.4% respectively.

Figures 7 and 8 show the consumer preference of the 3 PVA maize varieties, a commercial check and the local variety for Banku and Ga Kenkey. There were 40 respondents and more than 80% of them accepted the PVA maize varieties for food. They indicated that the new varieties were sticky and tasty with a nice flavor and were excellent for the dishes prepared and that the varieties had premium price over the traditional white. Their preferences was just similar to what was observed by Meenakshi et al. (2010); Hugo et al. (2010) and Stevens & Winter-Nelson (2008).

Table 19. Preliminary survey results of acceptability of Yellow/orange maize in 7 locations in the forest and transition zones of Ghana, 2015

Location	Total respondents	Strongly Like		Like		Moderately Like		Dislike	
		No.	%	No.	%	No.	%	No.	%
Akumadan	98	65	66.3	30	30.6	3	3.1	0	0
Aframso	62	59	95.2	3	4.8	0	0.0	0	0
Woraso	51	34	66.7	15	29.4	2	3.9	0	0
Fakawa	30	22	73.3	7	23.3	1	3.3	0	0
Amanase	54	46	85.2	8	14.8	0	0.0	0	0
Ejura market	26	24	92.3	2	7.7	0	0.0	0	0
Kwadaso Agric	58	42	72.4	13	22.4	3	5.2	0	0
TOTAL	379	292	77.0	78	20.6	9	2.4	0	0

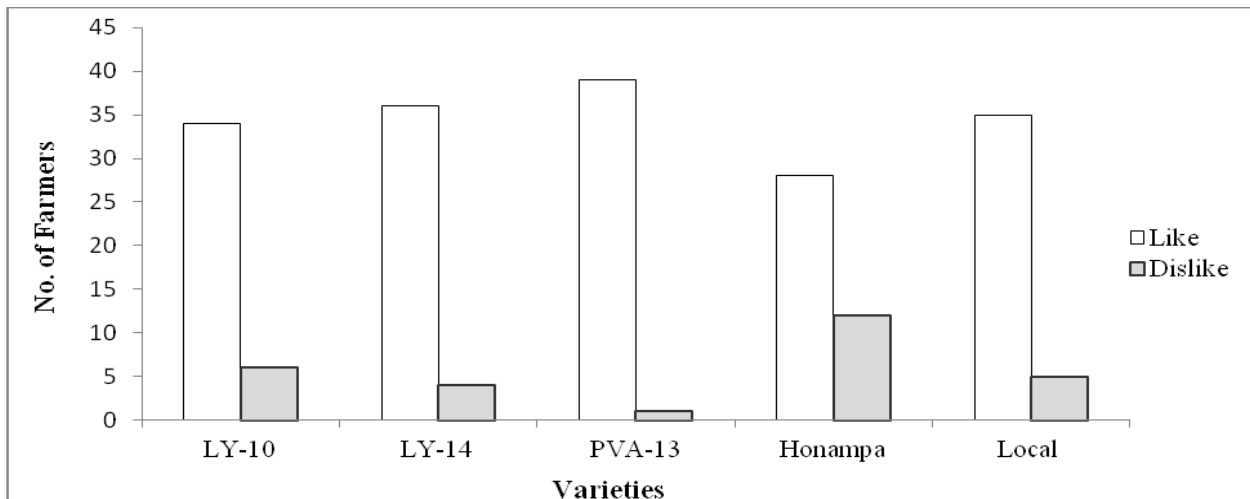


Fig. 7. Consumer preference of 3 PVA maize varieties compared with a commercial and local check: overall acceptability for Banku. LY-10=LY1001-10; LY14=LY1001-14; PVA-13=PVA SYN 13

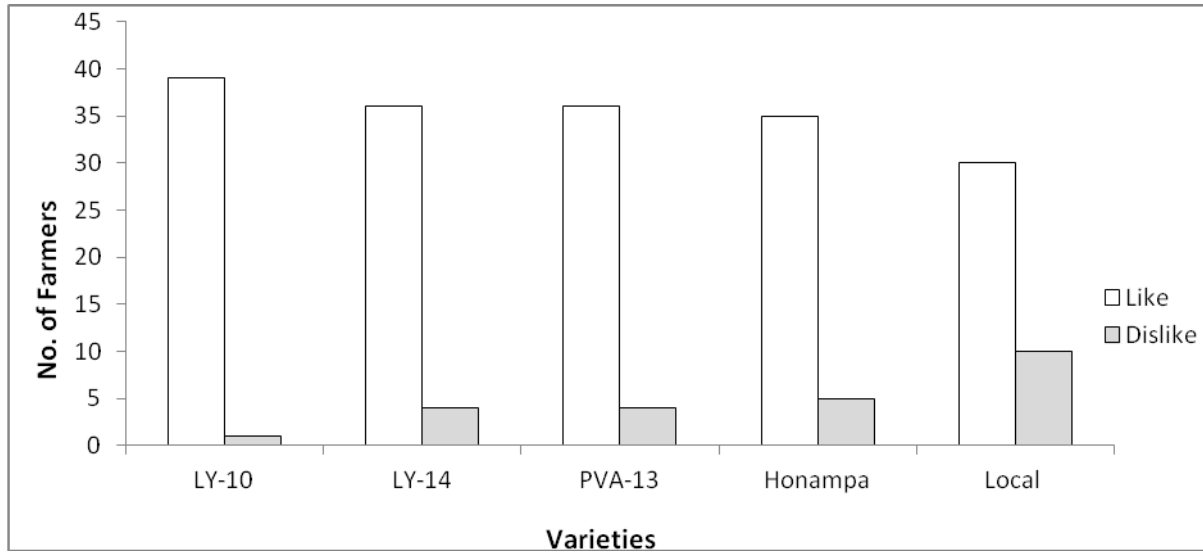


Fig. 8. Consumer preference of 3 PVA maize varieties compared with a commercial and local check: overall acceptability for Ga-Kenkey. LY-10=LY1001-10; LY14=LY1001-14; PVA-13=PVA SYN 13

3.6. Economic Analysis

Tables 20 and 21 show the partial budget analysis for PVA Synthetic and Hybrid maize varieties evaluated at Akumadan in 2013 production season. The results indicated that PVA SYN 13 had the highest net benefit of C3476. LY1001-14 and Odomfo had net benefits of C4959 and C3870 respectively. PVA SYN 9 had the lowest net benefit of C778. As regards the benefit cost ratios (BCR), except PVA SYN 9, all the other varieties had BCR of more than 1. This implied that they would all be beneficial for use by farmers. However LY1001-14 and

Odomfo had the highest BCRs of 3:1 and 2.3:1 respectively, indicating high profits of C2 and C1.30p per hectare respectively when one invests C1 per hectare in cultivating LY1001-14 and Odomfo. Tables 22 and 23 also show partial

budget analysis of PVA hybrid maize varieties and PVA Synthetic maize varieties in 2014 production year at Akumadan. LY1001-10 and Odomfo recorded high net benefits of C6164 and C2779 respectively in 2014. PVA SYN 13 also had net benefits of C2532 respectively which was substantial. LY1001-10 had the highest BCR of 3.25:1, an indication that one would recoup his or her investment of C1 per hectare plus an additional C2.25p per hectare. Similarly, LY1001-14 had a BCR of C1.33:1 which was higher than the farmer variety (C0.79:1). BCR shows the relation between the present value of the benefits and the present value of the costs. The investment is considered profitable if the benefit/cost ratio is higher than 1 (Maredia et al., 2000). The varieties LY1001-14, LY1001-10, and PVA SYN 13 would therefore increase farmers' incomes and improve food security if adopted.

Table 20. Partial budget analysis for 2 pro-vitamin A Synthetic maize varieties and a farmer variety tested on-farm at Akumadan in 2013.

	PVA SYN 13	PVA SYN 9	Farmer variety
Average yield (kg/ha)	2847	1348	2365
Adjusted yield(kg/ha)	2562.3	1213.2	2128.5
Gross benefit(C)	5124.6	2426.4	4257
Total cost that vary(C/ha)	1648.25	1648.25	1648.25
Net benefit(C/ha)	3476.35	778.15	2608.75
BCR	2.10	0.47	1.58

Table 21. Partial budget analysis for 2 pro-vitamin a hybrid maize varieties, a commercial check and farmer variety tested on-farm at Akumadan in 2013.

	LY1001-14	LY1001-10	ODOMFO	farmer variety
Average yield (kg/ha)	3671	2867	3066	2300
Adjusted yield(kg/ha)	3303.9	2580.3	2759.4	2070
Gross benefit(€)	6607.8	5160.6	5518.8	4140
Total cost that vary (€/ha)	1648.25	1648.25	1648.25	1648.25
Net benefit(€/ha)	4959.55	3512.35	3870.55	2491.75
BCR	3.00	2.13	2.34	1.51

Table 22. Partial budget analysis for 2 pro-vitamin a hybrid maize varieties, a commercial check and a farmer variety tested on-farm at Akumadan in 2014.

	LY1001-14	LY1001-10	Ɔdomfo	farmer variety
Average yield (kg/ha)	2454	4477	2596	1886
Adjusted yield(kg/ha)	2208.6	4029.3	2336.4	1697.4
Gross benefit(€)	4417.2	8058.6	4672.8	3394.8
Total cost that vary(€/ha)	1893.75	1893.75	1893.75	1893.75
Net benefit(€/ha)	2523.45	6164.85	2779.05	1501.05
BCR	1.332515	3.255366	1.467485	0.792634

Table 23. Partial budget analysis for 2 pro-vitamin a synthetic maize varieties and a farmer variety tested on-farm at Akumadan in 2014.

	PVA SYN 13	PVA SYN 9	Farmer variety
Average yield (kg/ha)	2459	1767	1696
Adjusted yield(kg/ha)	2213.1	1590.3	1526.4
Gross benefit(€)	4426.2	3180.6	3052.8
Total cost that vary(€/ha)	1893.75	1893.75	1893.75
Net benefit(€/ha)	2532.45	1286.85	1159.05
BCR	1.33	0.67	0.61

4. CONCLUSIONS

Three of the Pro-vitamin A maize varieties were recently released. These are made up of two 3-way hybrids (LY 1001-10), (LY 1001-14) and a synthetic or open pollinated variety (PVA SYN-13) named as Crops-Dzifoo (Akan language meaning Plenty), Crops-Ahoɔfe (Akan language meaning

beautiful) and Crops-Ahoɔdzin (Akan language meaning strength) respectively. The varieties are adapted to the major agro-ecologies in Ghana. Economic analysis indicated high net benefits for these new varieties and when adopted, will increase farmer income and reduce poverty in small holder farmers, thus addressing the sustainable development goal (SDG) 1 of poverty eradication. The varieties are rich in pro-vitamin A for improved health and nutrition and have the potential to solve malnutrition problems and this will address some aspects of the SDG goals 2 and 3 of reduction in child mortality and improvement in maternal health respectively.

Acknowledgements

This study was supported by HarvestPlus and West Africa Agricultural Productivity Programme and we are very grateful. We wish to thank staff of IITA especially Dr. Abebe Menkir for assisting in analyzing the carotenoid contents. The authors express their thanks to staff of CSIR-Crops Research Institute, CSIR-Savanna Agricultural Research Institute especially Dr. M. S. Abdulai and Mr. Alidu Haruna for assisting in field evaluations at Nyankpala. We are also grateful to the staff of Crops and Soil Science Department of Kwame Nkrumah University of Science and Technology especially Mr. S. J. Acquah for assisting in physico-chemical analysis. We also appreciate the immense efforts of the Ministry of Food and Agriculture and the variety release committee for getting the new varieties officially released to farmers.

REFERENCES

- Akposoe, M.K. 1971. Maize genetics, breeding and seed multiplication. A paper presented at a symposium on maize held on Monday April 5th and Tuesday April 6th 1971 at the Faculty of Agriculture, University of Science and Technology, Kumasi.
- Akposoe, M.K. 1975. The state of maize development and production in Ghana. Part I. Paper presented at seminar on the Policies for improving and expanding maize production in Africa, Addis Ababa. 24th–28th November, 1975.
- Allard, R.W. and Bradshaw, A.D. 1963. Implications of Genotype x Environment interactions in applied plant breeding. Paper delivered at the Annual Meeting of the Crop science societies of America, Denver, Colo., Nov. 20, 1963.
- Arshad, M., Bakhsh, A., Haqqani, A. M. and Bashir, M. 2003. Genotype-Environment Interaction for grain yield in Chickpea (*Cicer arietinum* L). *Pak. J. Bot.*35(2) pp.181-186.
- Asfaw, A. & Blair, M.W., 2014. Quantification of drought tolerance in Ethiopian common bean varieties. *Agricultural Sciences*. 5(2), pp.124–139.
- Badu-Apraku, B., Abamu, F. & Menkir, A., Fakorede, M.A.B. & Obeng-Antwi, K., 2003. Genotype by environment interactions in the regional early maize variety trials in West and Central Africa. *Maydica*.43:98-104. Available at: http://www.maydica.org/articles/48_093.pdf [Accessed December 30, 2015].
- Bhan, M., Pal, S., Rao, B.L., Dhar, A.K., Kang, M.S., 2005. GGE biplot analysis of oil Yield in lemongrass (*Cymbopogon* spp.). *Journal of New Seeds*. 7, pp.127-139. Available at: http://www.tandfonline.com/doi/abs/10.1300/J153v07n02_07 [Accessed January 28, 2016].
- Dehghani, H., Sabaghnia, N. & Moghaddam, M., 2009. Interpretation of genotype-by-environment interaction for late maize hybrids' grain yield using a biplot method. *Turkish Journal of Agriculture*, 33, pp.139–148. Available at: <http://journals.tubitak.gov.tr/agriculture/issues/tar-09-33-2/tar-33-2-5-0712-25.pdf> [Accessed December 30, 2015].
- Ding, M. Tier, B., and Yan, W., 2007. Application of GGE biplot analysis to evaluate Genotype (G), Environment (E) and GxE interaction on *P. radiata*: a case study. ... *Breeding for Wood* ..., p.16 pages. Available at: [http://www.researchgate.net/profile/Bruce_Tier/publication/228668679_Application_of_GGE_biplot_analysis_to_evaluate_Genotype_\(G\)_Environment_\(E\)_and_GxE_interaction_on_P_radiata_a_case_study/links/00b7d518832368fab0000000.pdf](http://www.researchgate.net/profile/Bruce_Tier/publication/228668679_Application_of_GGE_biplot_analysis_to_evaluate_Genotype_(G)_Environment_(E)_and_GxE_interaction_on_P_radiata_a_case_study/links/00b7d518832368fab0000000.pdf) [Accessed January 28, 2016].
- Distances 2016. www.distancesfrom.com/.../Fumesua
- Distancesto 2016. <https://www.distancesto.com/elevation/gh/ejura/history/36576.html>
- Elevationmap 2016. elevationmap.net/pokuase-ghana
- Facts and Figures. 2012. Ministry of Food and Agriculture. Statistics, Research and Information Directorate (SRID). 65pp.
- FAO 1997. Human nutrition in the developing world. FAO, Rome, Italy.
- FAO/WHO 2002. Human vitamin and mineral requirements. Report of a joint FAO/WHO expert consultation Bangkok, Thailand. Rome, Italy. [http://www.fao.org/documents/show_cdr.asp?url_file=/DOCR EP/004/Y2809E/Y2809E00.HTM]
- Farshadfar, E., Mohammadi R., Mostafa, A. & Vaisi, Z., 2012. GGE biplot analysis of genotype x environment interaction in wheat-barley disomic addition lines. *Australian Journal of Crop Science*. 6(6), pp.1074–1079. Available at: <http://search.informit.com.au/documentSummary;dn=734352271996269;res=IELHSS> [Accessed January 28, 2016].
- Gabriel, K.R. 1971. The biplot graphic of matrices with application to principal component analysis. *Biometrics* 58:453-467.
- Geek, W., 2016. Food analysis. Headspace analysis of characteristic VOCs www.gas-dortmund.de

Gittinger, J. P. (1982). Economic Analysis of Agricultural Projects. 2nd edition.

Horton S. M. Shekar, C. McDonald, A. Mahal and J.K. Brooks. 2009 Scaling Up Nutrition: What Will it Cost? World Bank Report. [World bank.org/nutrition/profiles](http://www.worldbank.org/nutrition/profiles)

Hugo, G., Keith, T., Haleegoah, J., Ewool, M., Benedicta, F., Banerji, A., Chowdury, S.K. and Meenaskshi, J.V. 2010. Assessing rural consumers' WTP for orange, biofortified maize in Ghana with experimental auctions and a simulated radio message. African Association of Agricultural Economists, 2010 AAAE Third Conference/AEASA 48th Conference, September 19-23, 2010, Cape Town, South Africa. <http://purl.umn.edu/96197>

Kiria, C.G, Vermeulen, H. and Hugo De Groote, H. 2010. Sensory Evaluation and Consumers' Willingness to Pay for Quality Protein Maize (QPM) using Experimental Auctions in Rural Tanzania. Contributed Paper presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19-23, 2010 pp.26

Kpotor, P., Akromah, R., Ewool, M.B., Kena, A. W., Owusu-Adjei, E. & Tuffour, H.O., 2014. Assessment of the Relative Yielding Abilities and Stability of Maize (*Zea mays* L) Genotypes under Different Levels of Nitrogen Fertilization across Two Agro- Ecological Zones in Ghana. *International Journal of Scientific Research in Agricultural Sciences*. 1(7), pp.128–141.

Maqbool, M.A., Aslam, M. & Ali, H., Shah, T.M. & Atta, B.M., 2015. GGE biplot analysis based selection of superior chickpea (*cicer arietinum* L.) inbred lines under variable water environments. *Pak. J. Bot.* 47(5), pp.1901-1908. Available at: https://www.researchgate.net/profile/Muhammad_Amir_Maqbool/publication/283485693_GGE_biplot_analysis_based_selection_of_superior_chickpea_Cicer_arietinum_L_inbred_lines_under_variable_water_environments/links/5641804708aebaae1f71ae9.pdf [Accessed January 28, 2016].

Maredia, M., Byerlee, D. and Anderson, J. (2000). Ex Post Evaluation of Economic Impacts of Agricultural Research Programs: A Tour of Good Practice. Paper presented to the Workshop on "The Future of Impact Assessment in CGIAR: Needs, Constraints, and Options", Standing Panel on Impact Assessment (SPIA) of the Technical Advisory Committee, Rome, May 3-5, 2000.

Meenakshi, J., Banerji, A. & Manyong, V., Tomlins, K., Priscilla, H., Rodah, Z. & Mungoma, C., 2010. Consumer

acceptance of provitamin A orange maize in rural Zambia (HarvestPlus Working Paper No. 4). Available at: http://gala.gre.ac.uk/11911/?utm_source=twitterfeed&utm_medium=twitter [Accessed February 16, 2016].

Mercer-Quarshie, H. 1980. Genotype x environment interactions in groundnut (*Arachis hypogea*) tests in Northern Ghana. *Oleagineux*, Vol 35 No.4 Avril 1980.

Mohamed, N.E.M., Said, A.A. & Amein, K.A., 2013. Additive main effects and multiplicative interaction (AMMI) and GGE-biplot analysis of genotype x environment interactions for grain yield in bread wheat (*Triticum aestivum* L). *African Journal of Agricultural Research*, 8(42), pp.5197–5203.

Nwalo, F., 2010. Rate of water absorption and proximate analysis of different varieties of maize in Ikwo Local Government Area of Ebonyi State, Nigeria. *African Journal of Biotechnology*, 9(52), pp. 8913-8917.

Obeng, H., 2000. Soil Classification in Ghana. Centre for Policy Analysis (CEPA), pp 1-35.

Olayiwola, M.O. & Ariyo, O.J., 2013. Relative discriminatory ability of GGE biplot and YS i in the analysis of genotype x environment interaction in Okra (*Abelmoschus esculentus*). *Int. J. Plant Breed. Genet.* 7, pp.146-158 Available at: <http://docsdrive.com/pdfs/academicjournals/ijpbjg/2013/146-158.pdf> [Accessed January 28, 2016].

Oladeji, B.S., Akanbi, C.T., Gbadamosi, S.O., 2013. Comparative studies of physico-chemical properties of yam (*Dioscorea rotundata*), cocoyam (*Colocasia taro*), breadfruit (*Artocarpus altilis*) and plantain (*Musa paradisiaca*) instant flours. *African Journal of Food Science*, 7(8), pp.210–215. Available at: <http://academicjournals.org/journal/AJFS/article-abstract/C59309312601>.

Otoo, E. & Asiedu, R., 2008. GGE biplot analysis of *Dioscorea rotundata* cultivar "DENTE" in Ghana. *African Journal of Agricultural Research*. 3(2), pp. 115-125. Available at: http://www.academicjournals.org/app/webroot/article/article1380880591_Otoo_and_Asiedu.pdf [Accessed January 28, 2016].

Pourdard, S. & Moghaddam, M., 2013. Study on seed yield stability of sunflower inbred lines through GGE biplot. *Helia*. 36(58), pp. 19-28. Available at: <http://www.degruyter.com/view/j/helia.2013.36.issue-58/hel1358019p/hel1358019p.xml> [Accessed January 28, 2016].

Sallah, P.Y.K, Abdulai, M.S. & Obeng-Antwi, K., 2004. Genotype x environment interactions in three maturity groups of maize cultivars. *African Crop Science Journal*. 12(2), pp.95-

104. Available at: <http://www.ajol.info/index.php/acsj/article/view/27667> [Accessed November 24, 2015].
- Shiri, M.R., 2013. Grain yield stability analysis of maize (*Zea mays* L.) hybrids under different drought stress conditions using GGE biplot analysis. *Crop Breeding Journal*. 3(2) pp.107-112. Available at: https://scholar.google.com/scholar?start=140&q=GGE+AND+Biplot&hl=en&as_sdt=0,5#3 [Accessed January 28, 2016].
- Sial, M. A., Arain, M. A. and Ahmad, M. 2000. Genotype x Environment Interaction on Bread Wheat Grown over Multiple Sites and Years in Pakistan. *Pak. J. Bot.* 32(1), pp.85-95.
- Sousa, L. & Hamawaki, O., Nogueira, A.P.O., Batista, R.O., Oliveira, V.M. & Hamawaki, R.L., 2015. Evaluation of soybean lines and environmental stratification using the AMMI, GGE biplot, and factor analysis methods. *Genetics and Molecular Research*. Available at: https://www.researchgate.net/profile/Renata_Batista3/publication/n/283016145_Evaluation_of_soybean_lines_and_environmental_stratification_using_the_AMMI_GGE_biplot_and_factor_analysis_methods/links/56266bd408aeabddac92faf3.pdf [Accessed January 28, 2016].
- Srivastava, R., Rathore, A., Vales, M. I., Kumar, R.V., Panwar, S. & Thanki, H.P., 2012. GGE biplot based assessment of yield stability, adaptability and mega-environment characterization for hybrid pigeonpea (*Cajanus cajan*). *Indian Journal of Agricultural Sciences*. 82(11), pp.928-933. Available at: <http://oar.icrisat.org/6211/> [Accessed January 28, 2016].
- Stanley O., Samonte, P.B., Wilson, L.T., McClung, A.M and Medley J.C., 2005. Targeting cultivars onto rice growing environments using AMMI and SREG GGE biplot analyses. *Crop Science*. Available at: <https://dl.sciencesocieties.org/publications/cs/abstracts/45/6/2414> [Accessed January 28, 2016].
- Stevens, R. & Winter-Nelson, A., 2008. Consumer acceptance of provitamin A-biofortified maize in Maputo, Mozambique. *Food Policy*. 33, pp. 341-351. Available at: <http://www.sciencedirect.com/science/article/pii/S030691920800031> [Accessed February 16, 2016].
- Tabien, E.R., Omar, S., Samonte, P.B., Abalos M.C. & Gabriel, R.C.S., 2008. GGE Biplot Analysis of Performance in Farmers' Fields, Disease Reaction and Grain Quality of Bacterial Leaf Blight-Resistance Rice Genotypes. *Phillippine Journal of Crop Science*, 33(1):03-19.
- UNICEF and Micronutrient Initiative. 2004. Vitamin and Mineral Deficiency; A Global Progress Report.
- Walter, R.F. 1993. Principles of cultivar development. Theory and Technique. Iowa State University. Vol.1. Published by Macmillan Publishing Company. p. 247.
- WHO 2003. Combating vitamin A deficiency. WHO website, updated September 2003. World Health Organisation, Rome, Italy. [<http://www.who.int/nut/vad.htm>]
- WHO 2016. *Micronutrient deficiencies: Vitamin A deficiency*. www.who.int/nutrition/topics/vad/en/
- Wikipedia 2016. <https://en.wikipedia.org/wiki/Kwadaso>
- Wikipedia 2016. <https://en.wikipedia.org/wiki/Ejura>
- Wikipedia 2016. <https://en.wikipedia.org/wiki/Akumadan>
- Wikipedia 2016. <https://en.wikipedia.org/wiki/Kpeve>
- Wikipedia 2016. <https://en.wikipedia.org/wiki/Nyankpala>
- World Bank. 2009. World Development Indicators (Database)
- Yan W, Hunt LA, Sheng Q, Szlavnic Z (2000). Cultivar evaluation and mega environment investigation based on the GGE biplot. *Crop Sci*. 40:597-605
- Yan, W. & Kang, M.S. (2003). GGE Biplot Analysis: a Graphical Tool for Breeders, *Geneticists and Agronomists*. CRC Press, Boca Raton.
- Yan, W., Kang, M.S., Ma, B., Wood, S. & Cornelius, P.L., 2007. GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science*. Available at: <https://dl.sciencesocieties.org/publications/cs/abstracts/47/2/643> [Accessed December 30, 2015].
- Yan, W. & Tinker, N., 2006. Biplot analysis of multi-environment trial data: Principles and applications. *Canadian Journal of Plant Science*. Available at: <http://pubs.aic.ca/doi/abs/10.4141/P05-169> [Accessed January 28, 2016]
- Yogesh., C.T. 2014. Water Binding Capacity. http://www.research.gate.net/profile/YOGESH_TRIPATHI