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Adaptability of Quinoa (*Chenopodium quinoa* Wild) in Eastern and Southern Africa: Potential implications for food security and climate change adaptation

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Collaborators

- Ministry of Agriculture Ethiopia
- Ministry of Agriculture Kenya
- Ministry of Agriculture Uganda
- Ministry of Agriculture Zambia
- Ethiopian Institute of Agricultural Research (EIAR)
- Kenya Agricultural and Livestock Research Organisation (KARLO)
- National Agricultural Crops Resources Research Institute (NaCRRI), Uganda
- Zambia Agricultural Research Institute, (ZARI)
- International Centre for Tropical Agriculture (CIAT)
- Lilongwe University of Agriculture and Natural Resources (LUANAR)]
- Food and Agricultural Organisation of the United Nations (FAO)

Introduction

- Quinoa is **nutritionally superior**; the only plant-based food that contains all the essential amino acids, trace elements and vitamins and contains no gluten

- Quinoa is greatly **adaptable to climate variability** and can survive in a wide variety of growing conditions

- Little is known about Quinoa in eastern and southern Africa

- Quinoa cultivation in Africa is an opportunity for commodity diversification, and response to threats to food and nutrition security posed by the current changes in climatic conditions

Objectives of the Exploratory study

- Introduce Quinoa in food systems of East and southern Africa
- Study the adaptability potential in African environments and identify high performing varieties
- Expose Quinoa as a crop to African plant breeders and build their capacity to evaluate quinoa in the national research systems
- Identify the major production constraints to quinoa production in selected African countries

Materials and Methods

- Ten quinoa cultivars different origins
- Amaranth Gold as a check

Variety	Origin	Source
Brightest Brilliant Rainbow	Oregon, US	LUANAR-Malawi
Bio-Bio	Chile	"
Cherry Vanilla	Oregon, US	"
Multi-Hued	B C, Canada	"
Titicaca	Denmark	"
Blanca de Junín	Peru	FAO
Amarilla Sacaca	Peru	"
Amarilla Maranganí	Peru	"
Salcedo INIA	Peru	"
Kancolla	Peru	"
Amaranth	Uganda	CHECK

Test Environments

Country	Environments	Altitude (M)		Rainfall (Mm)	Temperature (°C)
Ethiopia	Melkassa	1550	H	928	12.6-28.5
	Ziway	1575	H	728	12.9-29.8
	Arsi Negele		H		
Kenya	Embu	1511	M	1200-1400	18.9-20.1
	Karuangi	1292	M	1200-1340	20.4-20.9
	Mitunguu/Tunyai	964	L	820-920	21-23.5
Uganda	NACRRI	1180	M		
	BugiZARDI	1800	H		
	Kawand	1200	M		17.1-29.8
	Nabuin		H		
Zambia	Mount Makulu	1213	M	800-1200	-
	Mutanda	1304	M		
	Misamfu	1536	H		8.7- 26.4
	Nanga	934	L	531.9	

Trial establishment

- Randomized Complete Block Design (RCBD)
- Three replications
- Four row plot of 2 x 2m^2
- Drilling planting method
- Thinning to 50 x 10cm spacing: 80 plants
- Net plot: two centre rows per plot (≈ 40 plants)
- Spacing between plots; 0.50-1 m and 1-1.5m between replicates

Plate 1.Quinoa trail a Namulonge (NACRRI)-Uganda

Data collection

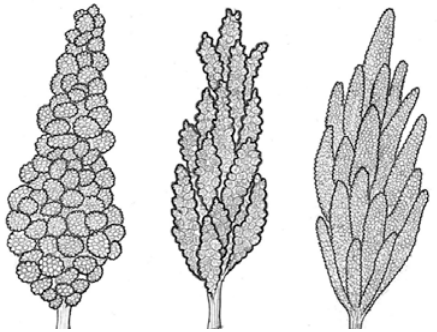
- Planting date
- Frequency and quantity of irrigation
- Type and timing of fertilizer application
- Harvesting date and net harvest area
- Emerging Date
- Plant Height (cm)
- Flowering Date at 50% (DF)
- Days from sowing to maturity
- Panicle length
- Branching architecture
- Seed yield/plot
- Yield/ha (YDHA)

Data analysis

- Breeding View tool of the Integrated breeding platform (The IBP Breeding Management System Version 3.0.8 (2015)
- Single site analysis
- G x E -Finlay Wilkinson model (FW)
- Additive main effect and multiplicative interaction (AMMI) model analysis
- Genotype main effects and genotype × environment interaction effects (GGE) model
- Estimation of stability and cultivar superiority

Morphological characteristics of 10 quinoa varieties at NARL-Kawanda and Embu

Variety	Panicle shape	Panicle color	Stem color	Plant architecture
Mult Hued	Glomerulate	Yellow/orange	Pink	Branched
Cherry Vanilla	Glomerulate	grey	Red	Single/Branched
Brightest Brilliant Rainbow	Intermediate/ Glomerulate	grey	Red	Single/Branched
Titicaca	Glomerulate	Yellow/orange	Yellow/pink	Single/Branched
Bio-Bio	Glomerulate	grey	Red	Single/Branched
SALCEDO INIA	Glomerulate	grey	Green	Branched/Single
BLANCA DE JUNIA	Glomerulate	yellow	Green	Branched
AMARILLA MARANGANI	Intermediate	red	Green	Branched
AMARILLA SACACA	Intermediate	Yellow/pink	Purple	Branched
KANCOLLA	Intermediate	purple	Purple	Branched/Single
Grain Amaranth Golden (Check)	Amarantiform	yellow	Yellow	Single



Glomerulate 2. Intermediate 3. Amarantiform

Plate 4: Panicle shape classifications (Bioversity International, FAO, PROINPA, INIAF and IFAD. 2013.)

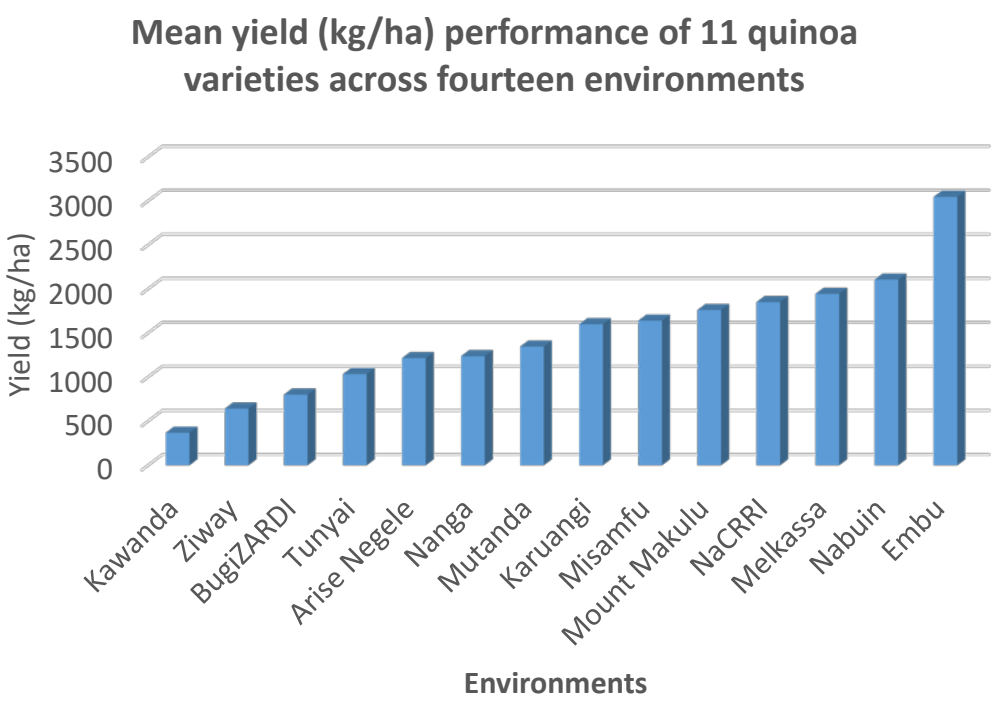
Variation in days to lowering (DF) and days to maturity (DPM) among 10 quinoa varieties across thirteen sites

Environment	Altitude	Days to 50% flowering (DF)			Days to physiological maturity (DPM)		
		Mean	Range	SD	Mean	Range	SD
Misamfu	H	42	40-46	2.039	114	96-146	17.42
BugiZARDI	H	55	50-59	2.430	114	87-141	21.86
Nabuin	H	33	31-36	1.586	72	68-83	3.77
Melkassa	H		-	-	83	81-87	2.31
Embu	H	44	42-47	1.848	110	82-158	26.93
Ziway	H	-	-	-	91	85-99	6.23
Arsi Negele	M	-	-	-	92	80-105	10.79
Mount Makulu	M	41	37-47	3.371	92	88-95	2.11
Mutanda	M	54	54	0.192	**150**	120-172	25.69
Kawanda	M	39	36-43	2.152	90.3	79-105	8.33
NaCRRI	M	56	53-66	3.629	-	-	-
Karuangi	M	31	26-37	4.569	98	87-116	10.53
Nanga	L	42	38-47	2.185	116	112-122	3.08
Tunyai	L	34	29-41	4.132	98	81-117	13.65

Variation in panicle length and plant height of 10 quinoa varieties across fourteen sites

		Panicle length (cm)			Plant height (cm)		
Environment	Altitude	Mean	Range	SD	Mean	Range	SD
Misamfu	H	25.67	17.7-34.6	5.79	85.42	52.2—121.5	21.57
BugiZARDI	H	16.52	14.8-19.7	1.27	**39.83**	32.7-45.8	4.02
Nabuin	H	28.21	23.2-38.0	3.87	76.80	58.6-116.6	14.63
Melkassa	H	19.47	14.7-32.1	5.64	85.02	58.3-109.5	17.11
Ziway	H	**14.24**	8.9-25.1	4.87	62.91	42.8-72.9	10.37
Embu	H	**84.68**	62.5-107.5	14.5	**142.91**	101-183	27.52
Mount Makulu	M	29.68	22.9-45	7.17	103.10	83.5-122.1	10.24
Mutanda	M	16.51	14.9-18.0	0.94	89.45	72.9-117.2	13.08
Karuangi	M	31.95	20.2-49.9	10.16	118.24	89.5-145.8	22.10
Kawanda	M	67.23	64.7-72.2	2.49			
NaCRRI	M	35.10	32.8-41.2	3.41	116.11	99.5-133.5	10.01
Arsi Negele	M	17.81	12.5-22.1	2.77	67.66	46.1-84.8	11.93
Nanga	L	39.87	30.5-51.8	7.35	120.65	89.1-153.9	23.66
Tunyai	L	31.82	20-50	10.38	108.82	84-138	19.64

Yield (kg/ha) performance across 14 environments

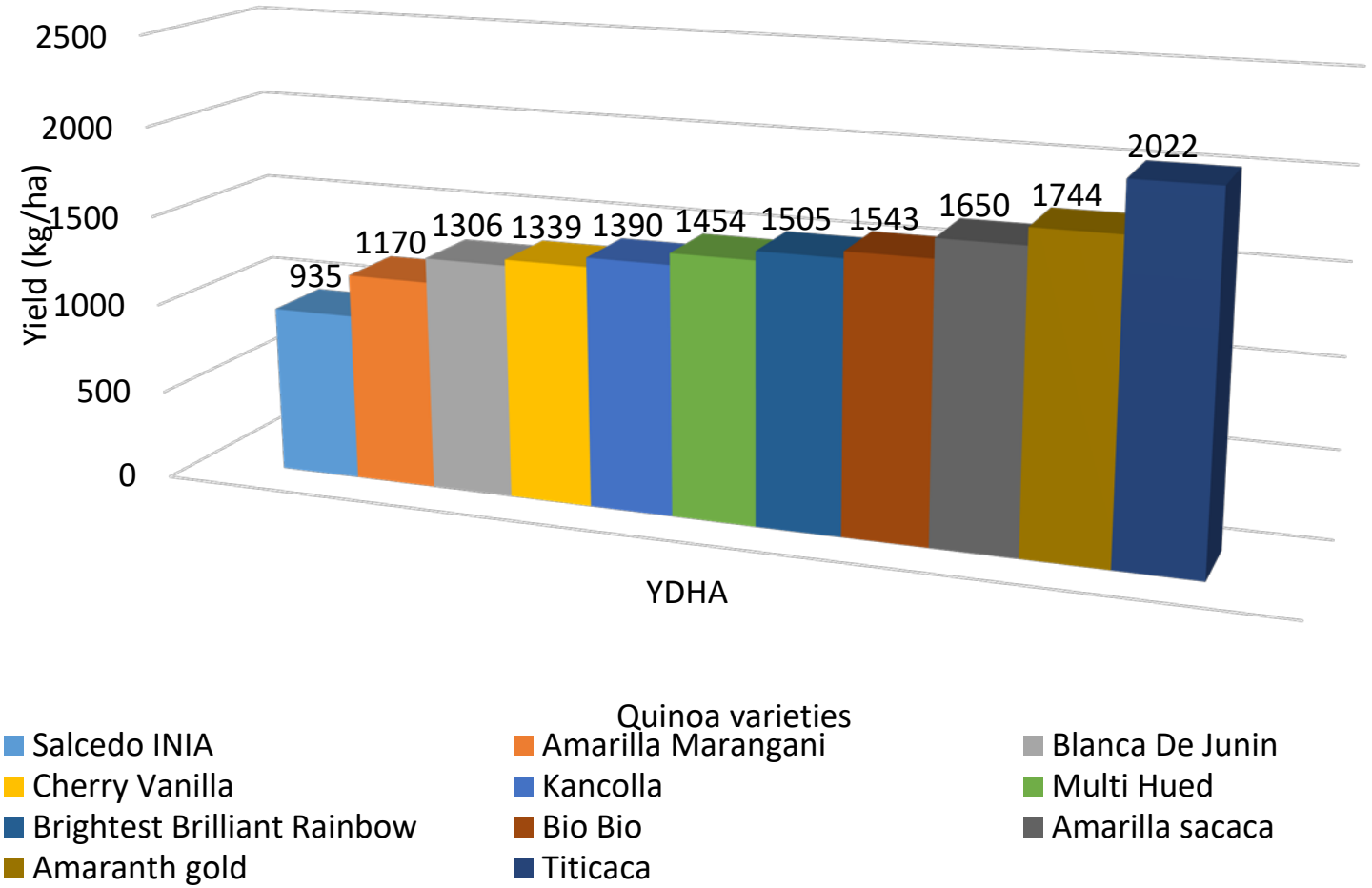


Environment	Min	Max	SD
Misamfu	1176.7	2364	411.2
Mount Makulu	765.7	2726	760.4
Mutanda	297.7	3011	715.1
Nanga	1183.6	1301	26.8
Kawanda	155.4	974	237.0
NaCRRI	1134.7	2891	584.5
BugiZARDI	671.5	1033	105.0
Nabuin	1537.1	2684	327.0
Arsi Negele	169.9	2928	1113.1
Melkassa	40.0	**4411**	1411.9
Ziway	40.4	3950	1340.9
Embu	1542.0	**4468**	924.6
Tunyai	254.0	2052	597.3
Karuangi	898.0	2800	667.6

Mean agronomic performance of 10 quinoa varieties

Genotype	DF	DPM	Panicle length (cm)	Plant height (cm)
Amaranth gold	43.15	98.9	36.16	93.34
Amarilla Marangani	42.4	108.7	36.02	108.57
Amarilla sacaca	44.39	105.7	32.02	92
Bio Bio	41.17	94.2	29.58	87.99
Blanca De Junin	43.56	112.8	36.38	100.11
Brightest Brilliant Rainbow	41.46	98.8	32.56	87.24
Cherry Vanilla	42.3	102.6	31.14	87.71
Kancolla	43.05	103	32.63	93
Multi Hued	42.79	96.9	30.8	98.09
Salcedo INIA	42.65	109.3	33.52	98.31
Titicaca	42.49	91.6	28.59	81.85

Yield (kg/ha) performance of 10 quinoa varieties across 13 environments



Sensitivities "*b*" of 10 quinoa varieties across 14 environments

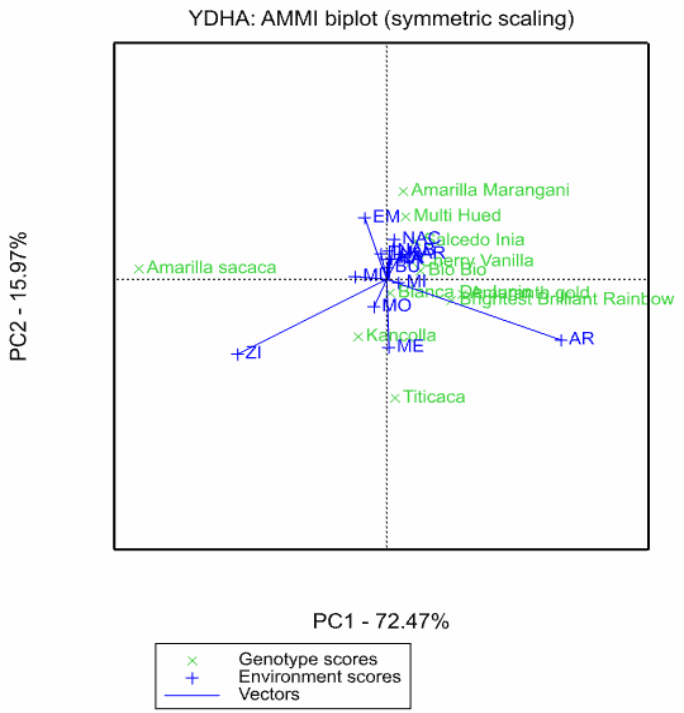
Genotype	DF	DPM**	Panicle length	Plant height	YDHA
Amaranth gold	0.92	0.55	**1.00**	1.12	0.81
Amarilla Marangani	0.89	1.20	1.27	1.33	1.51
Amarilla sacaca	0.91	0.63	1.24	1.34	1.29
Bio Bio	1.10	0.70	0.91	0.78	1.10
Blanca De Junin	0.84	1.33	1.14	1.22	0.86
Brightest Brilliant Rainbow	1.05	1.30	0.93	0.88	**0.98**
Cherry Vanilla	1.16	1.35	0.90	0.75	1.14
Kancolla	**0.99**	0.75	0.95	0.98	0.77
Multi Hued	1.05	1.29	0.92	**1.02**	1.40
Salcedo INIA	0.88	1.24	0.96	0.85	0.68
Titicaca	1.22	0.57	0.80	0.75	0.35

Additive main effects and multiplicative interaction (AMMI) model

Source	DF		DPM		Panicle length		Plant Height		Yield (kg/ha)	
	d.f.	s.s.	d.f.	s.s.	d.f.	s.s.	d.f.	s.s.	d.f.	s.s.
Genotypes	10	89	10	60753	10	29439	10	1277539	10	16943406
Environments	10	8939**	12	100607*	13	57383*	12	1703134	13	95704515**
Interactions	100	780**	120	616629**	130	318769**	120	15279908**	130	139143073**
IPCA 1	19	323**	21	593897**	22	313803**	21	15255412**	22	60392410**
IPCA 2	17	172**	19	10058**	20	3120**	19	12723**	20	44086428**
Residuals	64	284	80	12673	88	1846	80	11773	88	34664235

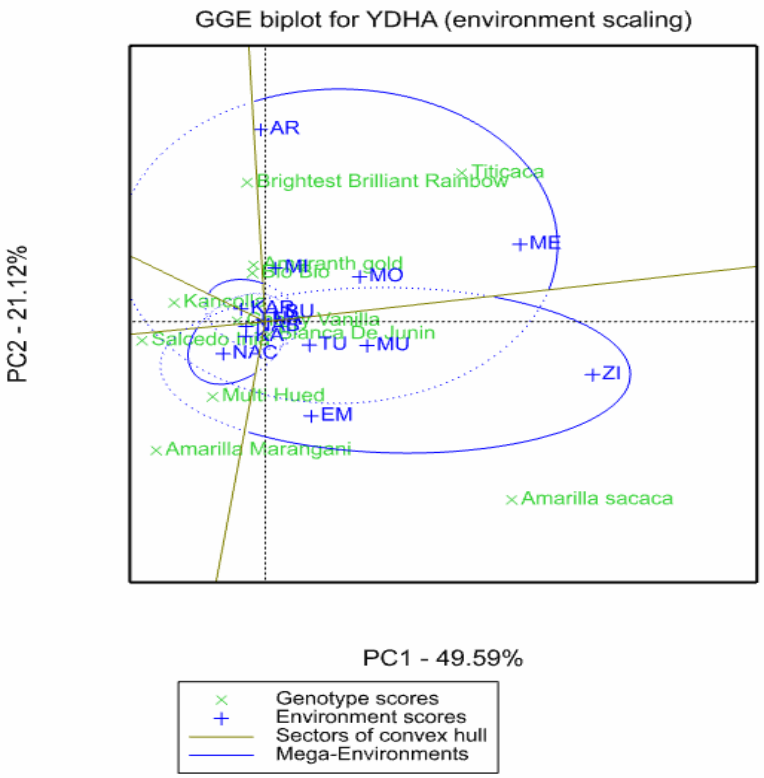
AMMI Bi plot for yield performance

- Highest genetic differences/variances were observed in Arsi Negele and Ziway (Ethiopia)
- These environments can be proposed as good test environments for yield evaluation



MI= Misamfu, MO= Mount Makulu
MU= Mutanda
NA= Nanga,
KA= Kawanda
NAC= NaCRRI
BU= BugiZARDI
NAB= Nabuin
AR=Arsi Negele
ME= Melkassa,
ZI =Ziway,
EM= Embu
TU= Tunyai
KAR=Karuangi

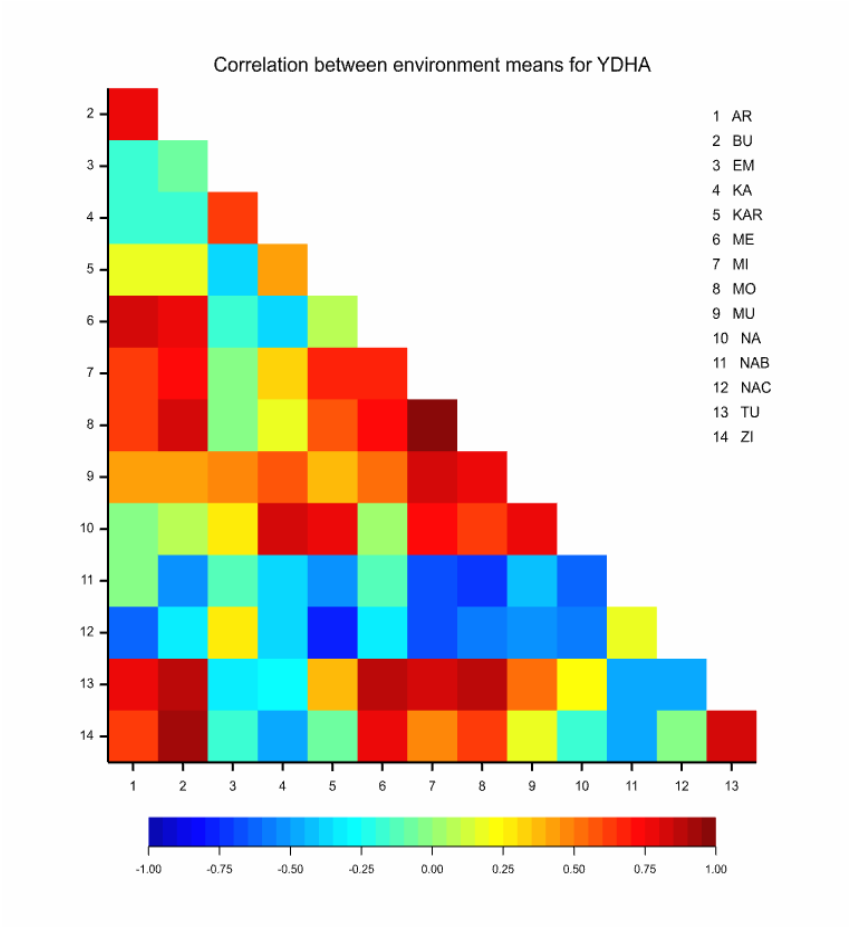
GGE biplot for yield performance



- Mega environment I:
  - Arsi Negele, Melkassa, Mount Makulu, Misamfu, Nanga, NaCRR, Kawanda, Karuangi, Tunyai
- Mega environment II:
  - Misamfu, Nanga, NaCRRI, Kawanda, Karuangi, Embu, Tunyai and Ziway
- Titicaca and Brilliant brightest Rainbow leading varieties (best performing) in Mega environment I
- Amarilla sacaca and Amarilla Marangani leading varieties in Mega environment II

Where:
MI= Misamfu, MO= Mount Makulu, MU= Mutanda, NA= Nanga, KA= Kawanda, NAC= NaCRRI, BU= BugiZARDI, NAB= Nabuin, AR=Arsi Negele
ME= Melkassa, ZI =Ziway, EM= Embu, TU= Tunyai, KAR=Karuangi

Correlation between environments

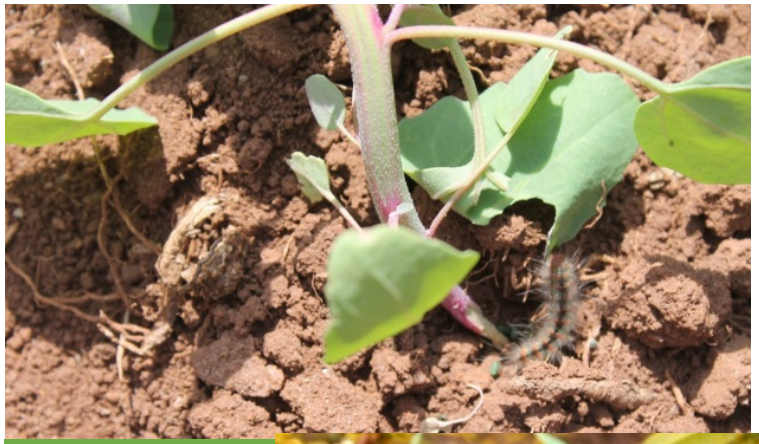


Where:
MI= Misamfu, MO= Mount Makulu, MU= Mutanda, NA= Nanga, KA= Kawanda, NAC= NaCRRI, BU= BugiZARDI, NAB= Nabuin, AR=Arsi Negele
ME= Melkassa, ZI =Ziway, EM= Embu, TU= Tunyai, KAR=Karuangi

- Misamfu and Mount Makulu highly positively correlated- similar ranking of yield performance of the varieties
- Positive correlations between, BugiZARDI (Uganda) and Ziway (Ethiopia), BugiZARDI and Tunyai (Kenya)
- Strong negative correlations between Karuangi (Kenya) and NACRRI (Uganda) indicating differences in these two environments

Pest observed

Aphids



Stem eating caterpillars

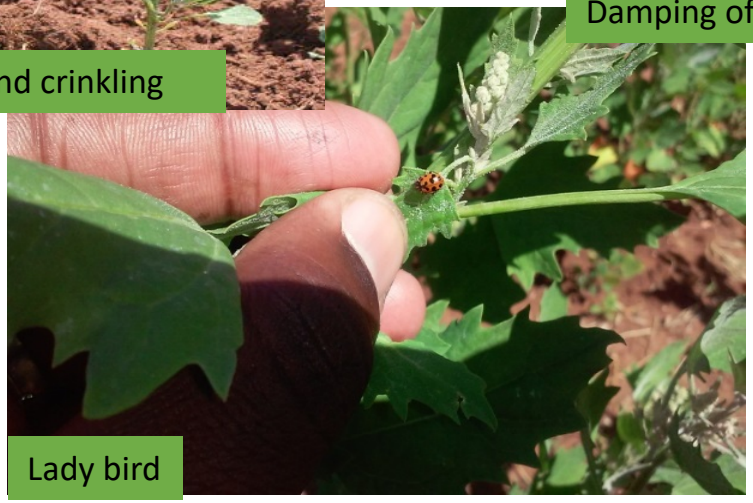
Leaf and panicle eating caterpillars

Panicle beetles

Other observations

Leaf shrinking and crinkling

Damping off



Lady bird

Termite attack

Conclusions

- Findings based on one crop season
- Cv Brilliant-brightest-rainbow most stable high yielding variety across all environments
- Cvs. Titicaca and Brilliant-brightest-rainbow best performing in nine environments
- Cvs. Amarilla sacaca and Amarilla marangani good performers in seven environments
- Altitude not a major factor influencing quinoa performance
  - Altitudinal differences, however, have a major influence on the prevailing climatic conditions of an area and hence this study provides evidence of quinoa as climate smart crop

Conclusions

- Several knowledge gaps to better understand Quinoa as a potential crop for introduction in the East African food
- Further field evaluations required
- Training in agronomy and characterisation of quinoa morphological characteristics (panicle shape, panicle colour, stem colors and growth habits) is required
- Awareness creation of quinoa as a potential new component of food systems and as a health food
- Nutrient analysis on-going

Acknowledgements

- FAO- Technical assistance for the strengthening of the Food System of Quinoa project