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Quinoa (*Chenopodium quinoa* Willd.) performance under the hot- dry weather of the Sudan

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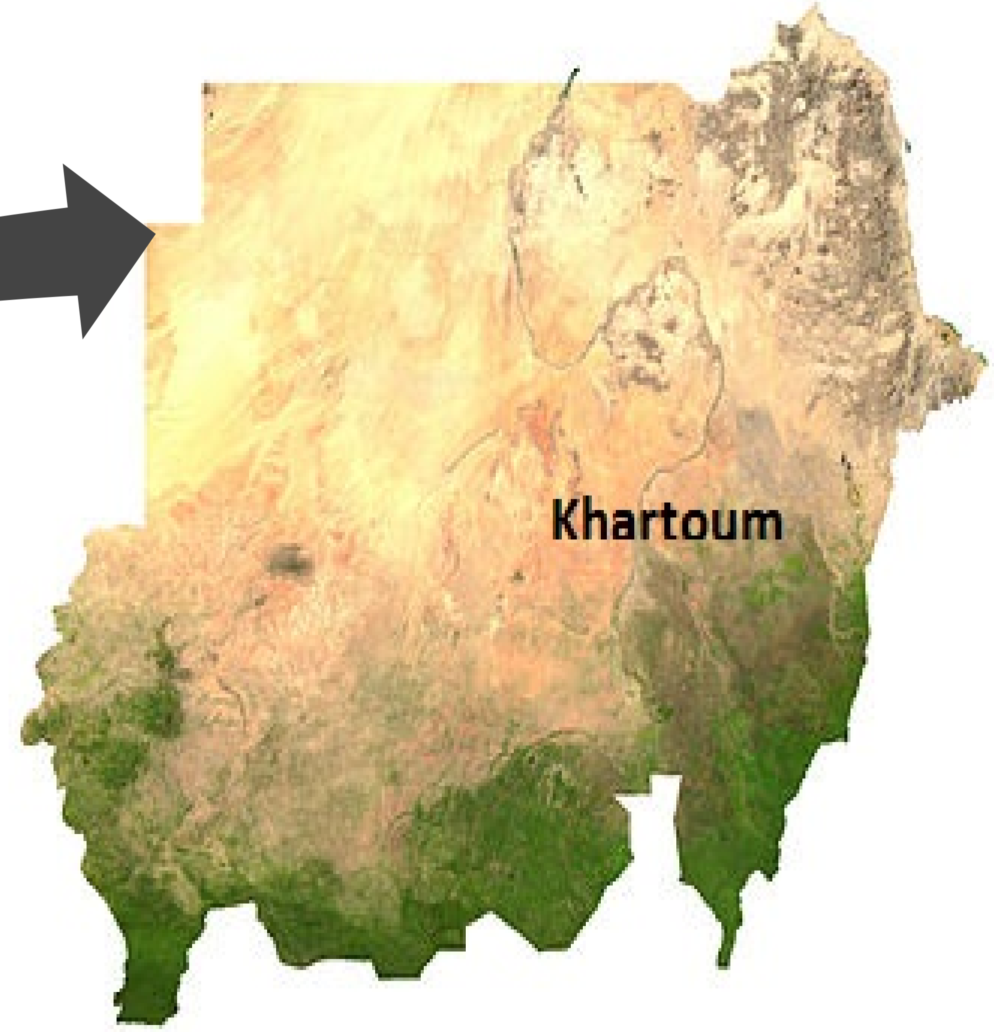


Sudan is well located in the Sub-Saharan & Sahelan zones

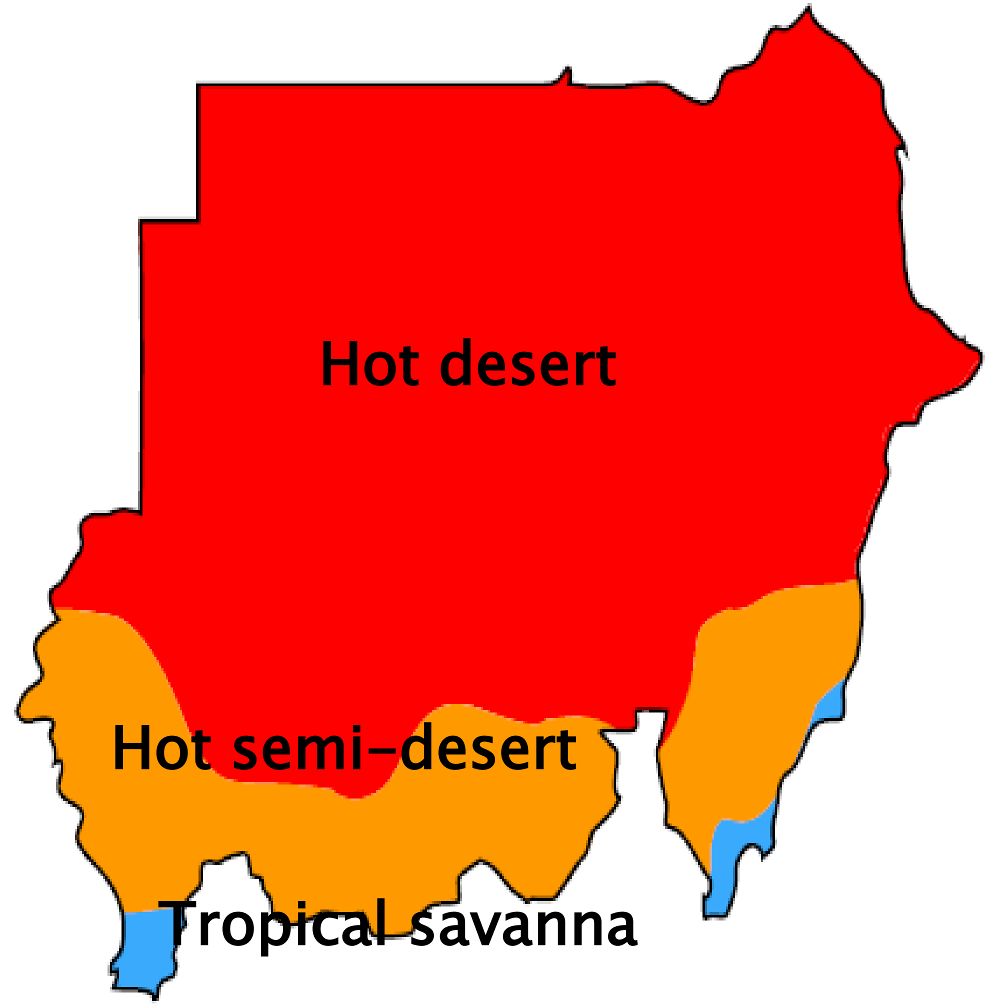
Introduction of quinoa to Sudan

- **Started in 2013 under the framework of the regional FAO project: TCP/RAB/3403**
- **Introduction of quinoa to Sudan can play a major role in overcoming food insecurity and fight malnutrition**
- **Represents new income generating option**

Major challenges facing quinoa cultivation in Sudan

- The hot dry weather
- Very short cool seaso

what ever sowing date you choose, the crop will be subjected to either early or terminal heat stresses at variable intensity



The objectives were to

- Investigate the potential of quinoa production in the Sudan,
- Identify quinoa materials tolerant to heat stress
- Understand the response of quinoa to early terminal heat stress

The paper presents two studies

- **Multi-location Study**

- **Heat stress study**

Multi-location Study: The environments

- 5 locations lying between lat. ranging 15˚ to 19˚ N ; Long. ranging 30˚ to 32˚ E . Elevation : 228 – 378 masl
- Soils : ranged from loamy clayey non-saline non-sodic soils to soils hazarded by salinity/sodicity complex . pH range 7.5 -7.9
- Growing season: temp 14.1°C - 44.5°C, rain fall: Non
- Crop failure occurred in 2 locations (Soba and Bagaer) and will not be reported

Multi-location Study: 19 genotypes tested in 5 locations

Designation	………… Location ………			Source
	Shambat	Merowe	Dongola	
Giza 1	X		X	Egypt Quinoa Program
Giza 2	X		X	Egypt Quinoa Program
Q 101(Amarilla manangare)	X	X	X	Peru (INIA†)
Q 102 (Amarilla sacaca)	X	X	X	Peru (INIA)
Q 103 (Blanca de junin)	X	X	X	Peru (INIA)
Q 104 (kancolla)	X	X	X	Peru (INIA)
Q 105 (Salcedo)	X	X	X	Peru (INIA)
Q 12	X	X		FAO Sudan (USDA)
Q 18	X	X		FAO Sudan (USDA)
Q 21	X	X		FAO Sudan (USDA)
Q 22	X			FAO Sudan (USDA)
Q 26	X	X		FAO Sudan (USDA)
Q 27	X	X		FAO Sudan (USDA)
Q 29	X	X		FAO Sudan (USDA)
Q 19		X		FAO Sudan (USDA)
Q 31 Regalona Baer		X		FAO Sudan
Santa Maria		X		FAO Sudan
Sajama		X		Iran Quinoa Program
Titicaca	X			Iran Quinoa Program
Total	15	15	7	

Multi-location study: Design & statistical analysis

- **Design: RCBD 3 Reps**
- **Analysis: ANOVA for single analysis and REML for combined analysis due to unbalanced set of entries (Patterson, 1997)**

Seed yield (t/ha)

Genotype	……….Location ………			Combined (3 locations)
	Shambat	Merowe	Dongola	
Giza 1	0.53	1.23	1.10	0.96
Giza 2	0.38	0.75	0.29	0.48
Q 101(Amarilla maranganí)	0.73	2.50	3.24	2.16
Q 102	0.44	0.61	3.11	1.39
Q 103	0.28	1.19	1.07	0.85
Q 104 (kancolla)	0.22	4.17	1.07	1.82
Q 105	0.18	2.66	1.69	1.51
Q 12	3.13	1.21		
Q 18	2.13	1.40	2.28	1.94
Q 21	1.69			
Q 22	1.82			
Q 26	2.96	1.48	2.74	2.39
Q 27	1.81	1.28		
Q 29	0.54	0.03		
Q 19		1.31		
Q 31		1.20		
Santa Maria		4.12		
Titicaca	4.50			

P. V. Genotypes (G) = <0.001
P. V. Locations (E) = 0.385
P. V. GxE = 0.002
S.E.D. GxE = .9631

G. Mean = 1.771
SE± = 0.2716
S.E.D = 0.5369

Days to Maturity & plant height

- **Titicaca, Giza 1, Q29 and Q22 were early maturing with less than 100 day maturity duration and short stature (65-90 cm)**
- **Q 101 through 105 (from Peru 'INIA') were late with maturity duration 148 to 156 days and tall stature (100-170 cm)**
- **Giza 2 and most of the FAO Sudan materials showed medium maturity duration (110-115 day)**

Early maturing Titicaca (Shambat, 2014/015)

Multi-location study: Conclusion

- The possibility exists for achieving good seed yield of quinoa under the hot weather of Sudan.
- Yield potentials can be maximized by manipulating the sowing date with growth duration of some promising cultivars.
- The very short cool season in the Sudan implies testing of quinoa germplasm under early and terminal heat stress.

Heat stress study :Testing under early and terminal heat stresses

- **The cool season is very short (little more than a month) not covering the whole growth period.**
- **Investigating the effect of heat stress at vegetative and reproductive stages is necessary.**

Early heat stress coincide with the vegetative stage

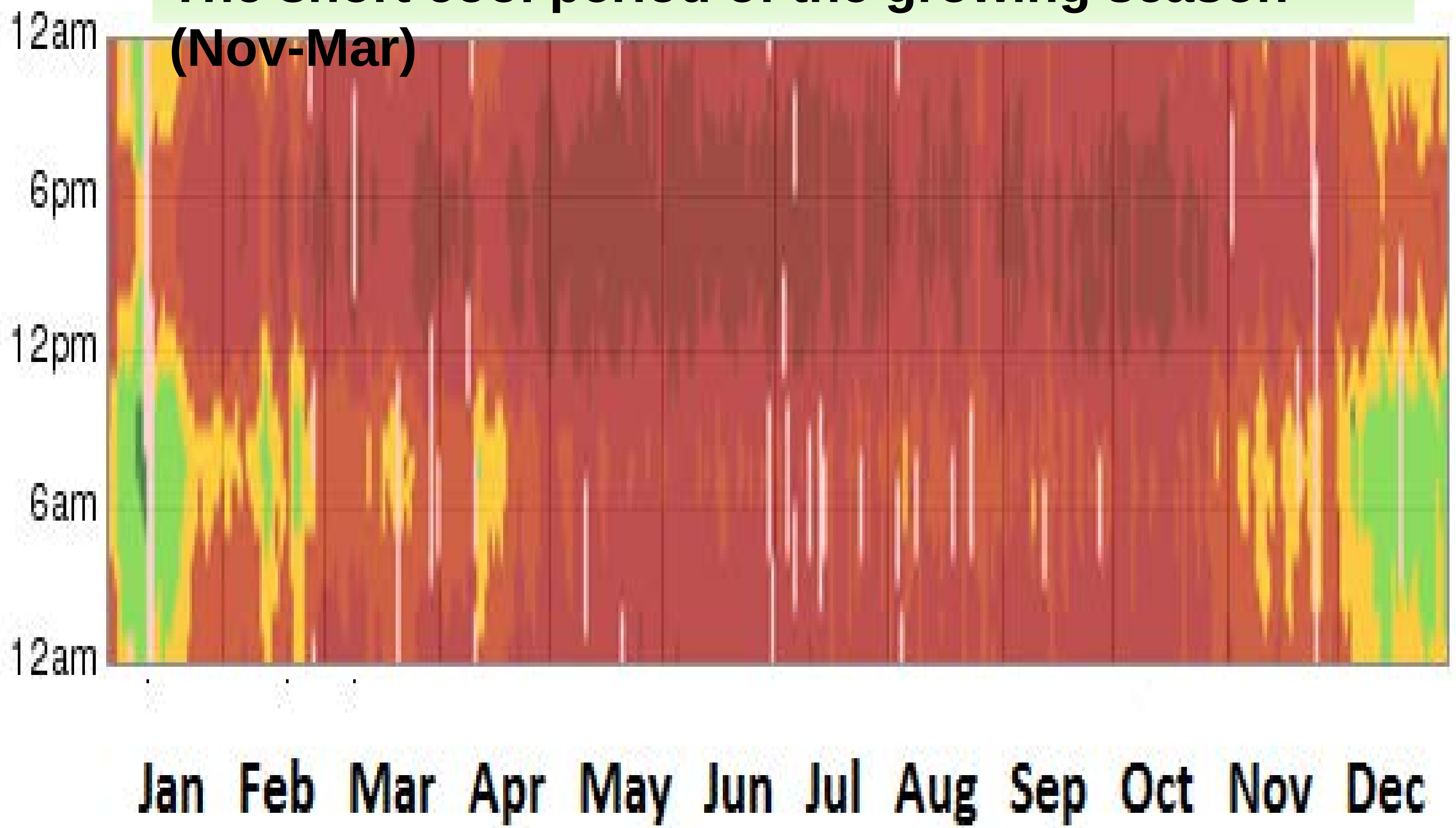
Terminal heat stress coincide with the reproductive stage

The short cool period of the growing season (Nov-Mar)

Hot = medium red (29°C - 38°C)

Extremely hot = dark red (> 38°C)

Cool = light green (10°C - 18°C),



Temperature daylight, rain fall and, humidity (Shambat, 2015)

Month	Max °C	Min °C	Daylight (H:M)/ Day	Total rain fall (mm)	Humidity (%)
Jan	32	16	11:18	0.0	25
Feb	34	17	11:36	0.0	19
Mar	37	19	12:01	0.0	15
Apr	40	23	12:28	0.0	11
May	42	26	12:50	0.2	13
Jun	42	27	13:01	1.4	25
Jul	38	26	12:56	13.9	44
Aug	36	25	12:37	42.6	51
Sep	38	25	12:11	18.0	41
Oct	40	25	11:45	1.0	26
Nov	36	21	11:22	0.0	22
Dec	33	17	11:12	0.0	25

The weather is hot and dry throughout most of the year

Steady increase in temperature and daylight could be noticed starting from Feb through Jun

Ten genotypes were subjected to early and terminal heat stresses

- **Six individual plant selections made within Titicaca, Q21 and Q104 + 4 genotypes : Giza1, Titicaca, Q21 and Rosada Huancayo.**
- **Sowing dates represent early (mid Nov 2015) and terminal (mid Jan 2016) heat stresses**
- **The design was RCBD with 2 rep. Combined ANOVA was performed. Simple linear regression with groups and correlations were performed.**

Data collected

1. Seed yield
2. Panicle threshing percentage (ratio of seed weight to total panicle weight expressed in percentage)
3. Maturity duration
4. Harvest index
5. Plant height

Panicle threshing % is taken to measure seed setting to identify genotypes tolerant to heat stress

Mean squares from analysis of variance

Source of variations	d.f.	Seed yield (t/ha)	Panicle threshing (%)	HI (%)	Plant height (cm)	Days to maturity
Rep	1	0.1109	648.18	200.84	71.33	8.4166
Genotype (G)	8	2.4185**	514.32**	104.56**	5626.49**	1709.432**
Sowing Time (ST)	1	20.2875**	8363.98**	1835.19**	4082.23**	4336.358**
GxST	8	0.9323**	124.13**	44.93*	162.82**	54.997**
Residual	12	0.1510	27.17	12.88	26.08	0.9508

Effect of early and terminal heat stress

Character	Early heat stress	Terminal heat stress	Mean	SE±	Difference (Terminal - early heat stress)
Seed yield (t/ha)	2.10	0.68	1.39	0.087	- 67.6%
Panicle threshing (%)	56.0	27.1	41.6	1.165	- 51.6 %
HI (%)	22.57	9.03	15.8	0.802	- 60 %
Plant height (cm)	128	148	138	1.142	+ 15.6 %
Days to					

Terminal heat stress caused large reduction in yield, panicle threshing % and HI, whereas plant height and days to maturity were significantly increased

Maturity duration under terminal heat stress ranged from 81 -148 days

- **The seed setting in genotypes with maturity duration exceeding 100 days will be fully exposed to elevated temperature during April or even May (Late maturing).**

- **The genotypes with 90 to 100 days maturity duration will be subjected to heat stress prevailing during March/April (Medium maturing)**

- **Genotypes with below 90 day maturity duration seed setting occurs during Feb/March and may partially escape the impact of high temperature at March (Early maturing)**

Interaction of genotype x early and terminal heat stress

- **S.Q104-4** , Late, v. good panicle threshing , good yield, heat tolerant
- **S.Q21-1** medium maturing, v. good panicle threshing, the best yielding, heat tolerant
- **S.Titicaca-1**, early, good panicle threshing, v. good yielding, heat escaper

Genotype	Seed yield (t/ha)		Panicle threshing (%)		Days to maturity	
	Early stress	Terminal stress	Early stress	Terminal stress	Early stress	Terminal stress
Giza1	1.03	0.36	62.8	33.0	93	110
Rosada	0.78	0.55	18.8	7.1	110	148
S.Q104-1	1.11	0.22	61.0	40.6	104	128
S.Q104-2	2.17	0.60	57.0	11.0	104	126
S.Q104-3	1.33	0.20	52.7	33.9	110	126
S.Q104-4	2.11	0.67	66.3	37.4	109	130
Q21	3.22	0.32	64.8	25.6	72	92
S.Q21-1	4.01	1.09	60.1	34.0	74	95
S.Titicaca-1	3.48	1.69	62.5	22.6	68	84
Titicaca	1.79	1.08	54.5	26.1	68	81
Mean	1.39		41.6		102	
SE±	0.275		3.686		0.689	
CV(%)	27.9		12.5		1.0	

Interaction of genotype x early and terminal heat stress

Genotype	Seed yield (t/ha)		HI (%)		Plant height (cm)	
	Early stress	Terminal stress	Early stress	Terminal stress	Early stress	Terminal stress
Giza1	1.03	0.36	29.7	11.70	61	75
Rosada	0.78	0.55	3.6	0.98	182	227
S.Q104-1	1.11	0.22	23.8	11.65	149	161
S.Q104-2	2.17	0.60	21.6	16.05	156	164
S.Q104-3	1.33	0.20	18.8	8.63	145	164
S.Q104-4	2.11	0.67	24.9	11.33	148	169
Q21	3.22	0.32	27.9	6.81	113	133
S.Q21-1	4.01	1.09	24.8	9.79	134	142
S.Titicaca-1	3.48	1.69	28.3	5.63	115	134
Titicaca	1.79	1.08	22.4	7.68	81	118
Mean	1.39		15.80		138	
[illegible]	[illegible]		[illegible]		[illegible]	

HI (%) kept similar trend as panicle percentage

Under terminal heat stress, all genotypes showed reduced HI(%) and increased plant ht

We should differentiate between early maturing and heat tolerant genotypes

- Early maturing genotypes give good seed yield by escaping terminal heat stress.
- True heat tolerant genotypes are those having the capacity for good seed setting under high temperature.
- Heat tolerant genotypes can be easily identified by measuring the panicle threshing percentage, a trait usually ignored in quinoa breeding for adaptation to heat stress

Character's associations

HI_%				
Days to maturity	-0.5279**			
Panicle threshing %	0.9812**	-0.5134**		
Plant height	-[illegible]	0.5608**	-0.4598*	
S[illegible]	0.6022**			
	HI_%	Days to	Panicle	Plant ht

These results disagree with those of many workers. The high temperature and the very short cool season favored early maturing – short statured genotypes

Response to selection for panicle threshing percentage is more effective under early heat stress.

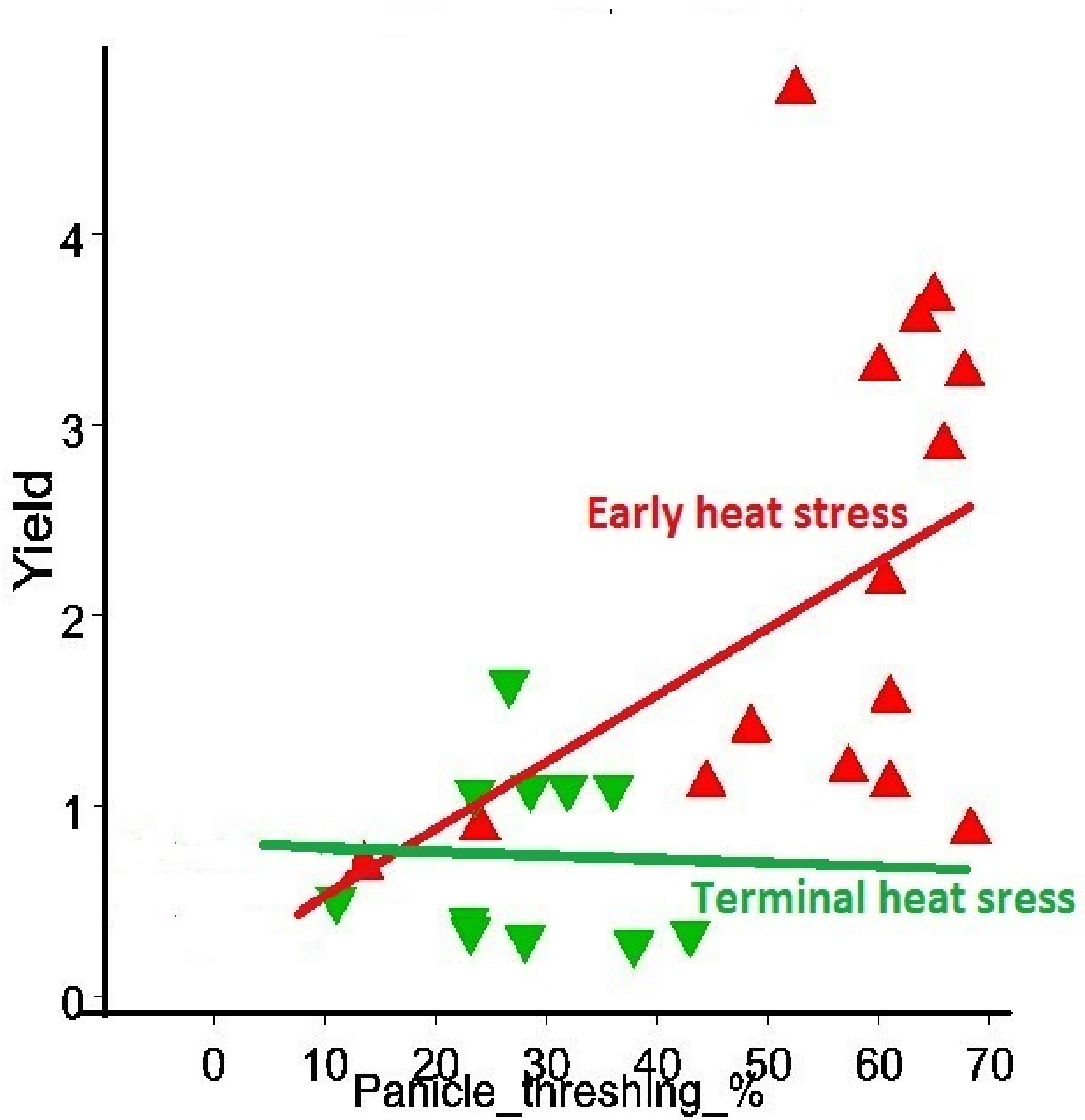


Fig. 1 Response of quinoa seed yield (t/ha) to panicle threshing % at early and terminal heat stresses

Response to selection for HI % is more effective under early heat stress.

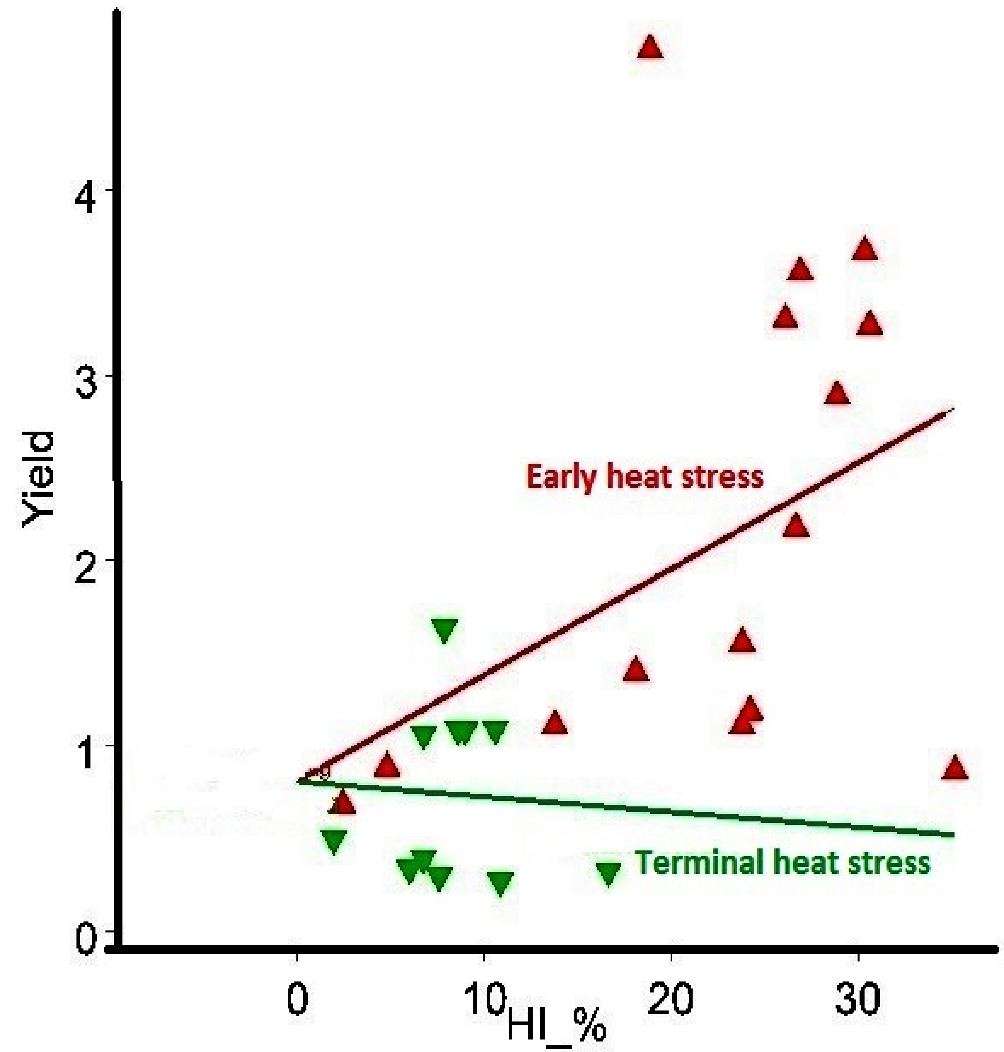


Fig. 2. Response of quinoa seed yield (t/ha) to HI % at early and terminal heat stresses

Dependence of yield of Q21 and Titicaca populations on panicle threshing % is stronger relative to other quinoa populations

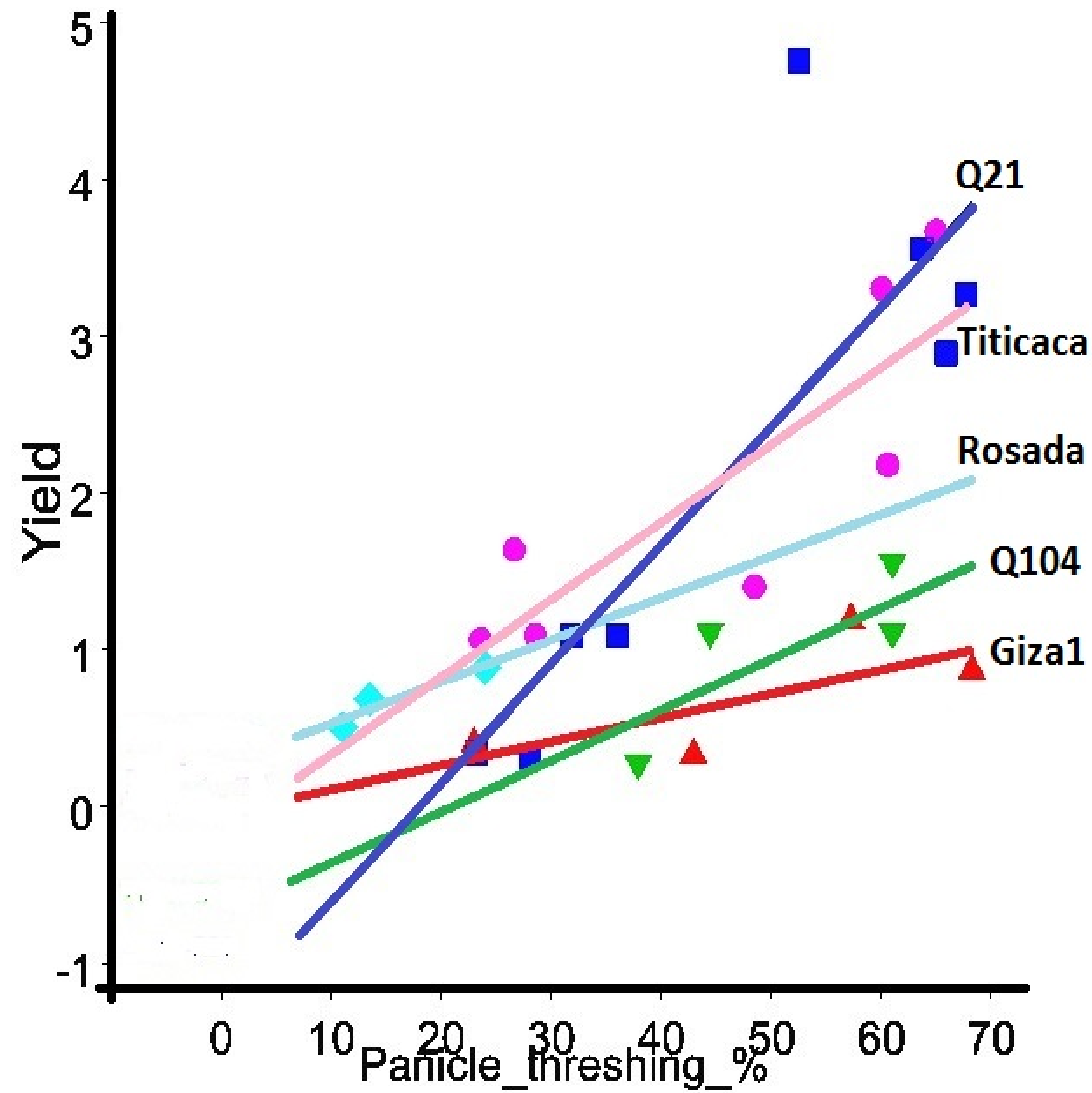


Fig. 3. Response of seed yield (t/ha) of five quinoa populations to panicle threshing percentage

Dependence of yield of Q21 and Titicaca populations on HI (%) is stronger relative to other quinoa populations

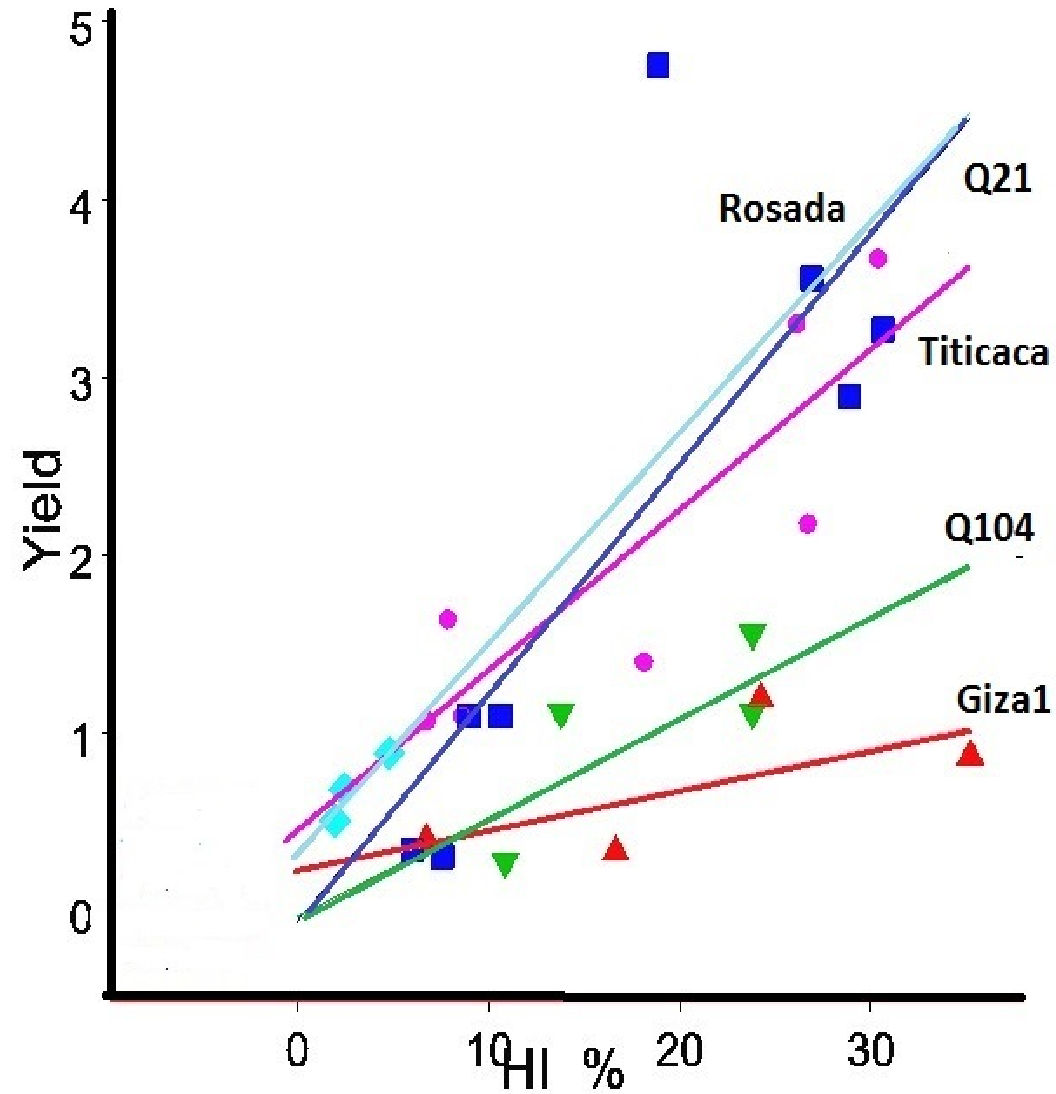
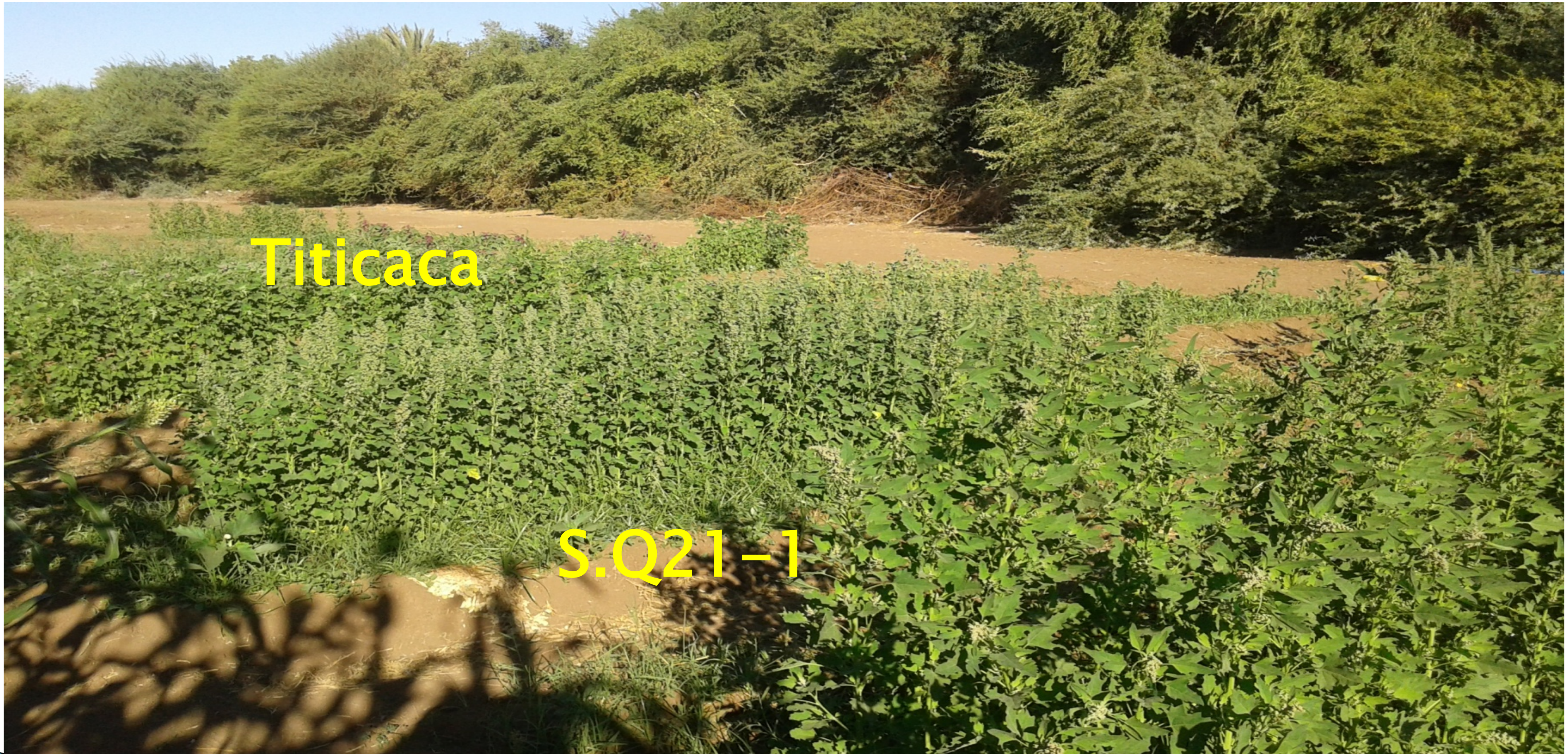


Fig. 4. Response of seed yield (t/ha) of five quinoa populations to HI (%)

Heat stress study : Conclusions

- Selection for Panicle threshing percentage is vital for developing quinoa cultivars tolerant to heat stress
- Selecting ultra early maturing (< 90 days) genotypes is recommended for quick quinoa adaptation to Sudan environment.
- To tap the full potential of quinoa, real heat tolerant genotypes with medium maturity duration need to be developed by screening and selection for panicle threshing percentage under early heat stress
- Titicaca and Q21 responded better to selection than other studied genotypes. Selection among both populations may give birth to the first candidates for commercial release in the Sudan

Shambt (2015/2016)




Q21
Titicaca


S. Titicaca-1


S. Titicaca-1

Thank you

Thank you

Thank you