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Selection of Salt-Tolerant Triticale (x Triticosecale Wittmack) Genotypes for Grain and Forage End-Uses

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Abstract: The objective of this work was to investigate salinity tolerance on a large panel of triticale composed of 801 genotypes being chosen among the international collection. In 2006/2007 cropping season, the collection was grown in field pots at 10 dS m^{-1}. Biomass and grain yields were equal to 57 and 8.5 g/pot, respectively. Multivariate analyses showed that 60% of the collection was suitable for grain production. About 134 genotypes (17% of the collection) were selected for 2007/2008 growing season, where the genotypes were grown at 5, 10 and 15 dS m^{-1}. The second pot screening cycle showed that top genotypes performed 40 and 30% higher grain and forage yields, respectively, at 15 dS m^{-1} than average yields of the collection grown at 5 dS m^{-1}. Whereas, high salinity level curtailed grain yield and forage yield of the whole collection by 38 and 35%, respectively. The two season's field pot screening allowed the selection of a nursery of 36 genotypes that were assessed during 2008/2009 season in field plots with three salinity levels: 5, 10 and 15 dS m^{-1} and three replications. The genotypes of the nursery differed at 89% for yield. At 15 dS m^{-1}, only 22% of the genotypes exceeded target values of forage and grain yields of 5 and 2 t ha^{-1}, respectively. Genotypes displaying stable grain and forage yields represented 16 and 41% of the final nursery.

Abbreviations: G x E ・ Genotype x environment interaction ・ GY ・ Grain yield ・ BY ・ Biomass yield ・ SY ・ straw yield

Key words: Salt-tolerant genotypes ・ International collection ・ Pot and field experiments ・ Nursery selection

INTRODUCTION

In context of farmer's strategies aiming to buffer the impacts on yield reduction due to intensity of salinity stress, tolerant genotypes would be grown. Moderately and highly salt-tolerant cereals could be used to diversify salt-affected lands [1].

Triticale is a flexible crop in term of adaptation to arid environments (high temperatures, drought) where irrigation water is saline and to semi-arid environments with diverse soil topographic sequence, particularly in clayey slums where water lodging and salinity are frequent. Straw production of the triticale crop is often higher then classical cereals such as wheat and barley. Consequently, triticale is highly useful for farming systems enclosing livestock that is a farmer income regulatory component.

Most of the research done on triticale response to salinity focused germination and seedling stages [2-4]. Accumulation of a higher Na^+ amount in the seeds rather than osmotic stress was responsible for delayed seed germination of triticale cultivars while it has no effect on final germination percentage. During early stages, increasing salinity levels reduces root and shoot dry weights of triticale [5-7].

The present work focused identification of salt tolerant genotypes among a sub-set of 801 genotypes originating from the international collection. Prior to this

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study, little information was available on field yield response to salinity of the collection in order to identify top performing genotypes for dual-purpose, forage and grain purposes end-uses. The genotypes of the collection evaluated were chosen for their known characteristics of specific adaptation to heat and drought frequent in semiarid and arid environments of the WANA region. We report here a three years salinity screening: 2006-2009. The first sreening was achieved in field pots where 801 genotypes were grown at one discriminating salinity of irrigation water equal to 10 dS m^{-1}. After records, only 17% of the collection was selected for a second screening where the selected genotypes were irrigated using three salinity levels: 5, 10 and 15 dS m^{-1}. In the third year, only 5% of the initial collection was grown under field conditions and in three salinity levels. Genotypes were clustered according to their purposes end-uses under each salinity level.

MATERIALS AND METHODS

Triticale Collection: Screened triticale collection is constituted of 801 genotypes that are representative of the whole international collection (Table 1). Experiments were achieved at the Experiment Station of the International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates (25° 13’ and 55°17’E). Experiments included field pot screening for salinity tolerance during 2006/2007 and 2007/2008, plus one field plot experiment achieved during 2008/2009 growing season.

Pot Experiments: In the first step, the entire collection was grown in outdoor pots under one discriminating water salinity equal to 10 dS m^{-1} over the first growing season 2006/2007. For each pot the substratum was composed of a mixture of 18 kg dune

Table 1: Triticale collection composed of 801 genotypes chosen among the international collection. Codes correspond to genotypes's ID as defined by IPIGRI.

Code	ID	Code	ID	Code	ID	Code	ID	Code	ID	Code	ID	Code	ID
1	6TA201	41	PI 381432	77	PI 386141	113	PI 388692	150	PI 414961	186	PI 428739	222	PI 428804
2	6TA203	42	PI 381433	78	PI 386142	114	PI 388693	151	PI 414962	187	PI 428740	223	PI 428805
3	6TA204	43	PI 381435	79	PI 386143	115	PI 388694	152	PI 414963	188	PI 428742	224	PI 428806
4	6TA204-33	44	PI 381437	80	PI 386144	116	PI 388695	153	PI 414964	189	PI 428743	225	PI 428809
5	6TA204-38	45	PI 381438	81	PI 386149	117	PI 388696	154	PI 414965	190	PI 428744	226	PI 428811
6	6TA205-21	46	PI 383408	82	PI 386150	118	PI 388697	155	PI 414966	191	PI 428745	227	PI 428814
7	6TA206-20	47	PI 383409	83	PI 386151	119	PI 388699	156	PI 414967	192	PI 428747	229	PI 428816
9	6TA209-19	48	PI 386000	84	PI 386152	120	PI 405019	157	PI 414968	193	PI 428748	230	PI 428818
10	6TA209-22	49	PI 386001	85	PI 386153	121	PI 405020	158	PI 414969	194	PI 428750	231	PI 428819
11	6TA210	50	PI 386003	86	PI 386154	122	PI 405024	159	PI 414970	195	PI 428753	232	PI 428820
12	6TA213	51	PI 386004	87	PI 386156	123	PI 405025	160	PI 414972	196	PI 428754	234	PI 428824
13	6TA386	52	PI 386005	88	PI 386157	124	PI 405026	161	PI 414973	197	PI 428755	235	PI 428826
14	6TA427	53	PI 386113	89	PI 388655	125	PI 405027	162	PI 414974	198	PI 428756	236	PI 428827
15	Alberta I-27-11	54	PI 386114	90	PI 388656	126	PI 405028	163	PI 422258	199	PI 428757	237	PI 428836
17	AM 2147	55	PI 386115	91	PI 388657	127	PI 405029	164	PI 422259	200	PI 428758	238	PI 428839
18	China1	56	PI 386116	92	PI 388660	129	PI 405031	165	PI 422260	201	PI 428759	239	PI 428840
19	China2	57	PI 386117	93	PI 388662	130	PI 405032	166	PI 422261	202	PI 428760	240	PI 428841
20	China3	58	PI 386118	94	PI 388664	131	PI 405033	167	PI 422262	203	PI 428762	241	PI 428842
21	Graze70	59	PI 386119	95	PI 388665	132	PI 405034	168	PI 422263	204	PI 428764	242	PI 428844
22	H 390	60	PI 386120	96	PI 388666	133	PI 410802	169	PI 422264	205	PI 428765	243	PI 428845
23	PI 280457	61	PI 386123	97	PI 388667	134	PI 410803	170	PI 422265	206	PI 428768	244	PI 428846
24	PI 282899	62	PI 386124	98	PI 388668	135	PI 410804	171	PI 422266	207	PI 428769	245	PI 428847
25	PI 285753	63	PI 386125	99	PI 388669	136	PI 410805	172	PI 422267	208	PI 428773	246	PI 428848
26	PI 308880	64	PI 386126	100	PI 388670	137	PI 410806	173	PI 422268	209	PI 428777	247	PI 428849
28	PI 320250	65	PI 386127	101	PI 388671	138	PI 410807	174	PI 422269	210	PI 428780	248	PI 428851
30	PI 340749	66	PI 386128	102	PI 388672	139	PI 410809	175	PI 422270	211	PI 428781	249	PI 428854
31	PI 351662	67	PI 386130	103	PI 388673	140	PI 410883	176	PI 422271	212	PI 428787	250	PI 428866
32	PI 355948	68	PI 386131	104	PI 388676	141	PI 410904	177	PI 422279	213	PI 428792	251	PI 428868
33	PI 355949	69	PI 386132	105	PI 388677	142	PI 410906	178	PI 422288	214	PI 428793	252	PI 428870
34	PI 355951	70	PI 386133	106	PI 388678	143	PI 413008	179	PI 428729	215	PI 428794	253	PI 428873
35	PI 355952	71	PI 386134	107	PI 388680	144	PI 414626	180	PI 428730	216	PI 428795	254	PI 428875
36	PI 355953	72	PI 386135	108	PI 388683	145	PI 414627	181	PI 428731	217	PI 428796	255	PI 428876
37	PI 355954	73	PI 386137	109	PI 388684	146	PI 414943	182	PI 428732	218	PI 428798	256	PI 428878
38	PI 368166	74	PI 386138	110	PI 388688	147	PI 414944	183	PI 428733	219	PI 428799	257	PI 428879
39	PI 381429	75	PI 386139	111	PI 388690	148	PI 414959	184	PI 428736	220	PI 428800	258	PI 428880
40	PI 381430	76	PI 386140	112	PI 388691	149	PI 414960	185	PI 428738	221	PI 428801	259	PI 428881
260	PI 428882	296	PI 428941	332	PI 428986	368	PI 429034	405	PI 429085	441	PI 429126	477	PI 429166
261	PI 428883	297	PI 428943	333	PI 428987	369	PI 429038	406	PI 429086	442	PI 429128	478	PI 429167
262	PI 428884	298	PI 428945	334	PI 428988	370	PI 429040	407	PI 429087	443	PI 429129	479	PI 429168
263	PI 428897	299	PI 428946	335	PI 428989	371	PI 429041	408	PI 429088	444	PI 429133	480	PI 429171

table 1: Continue

Code	ID	Code	ID	Code	ID	Code	ID	Code	ID	Code	ID	Code	ID
264	PI 428898	300	PI 428949	336	PI 428991	372	PI 429042	409	PI 429089	445	PI 429134	481	PI 429173
265	PI 428899	301	PI 428950	337	PI 428992	373	PI 429043	410	PI 429090	446	PI 429135	482	PI 429174
266	PI 428901	302	PI 428951	338	PI 428993	374	PI 429044	411	PI 429091	447	PI 429136	483	PI 429175
267	PI 428902	303	PI 428952	339	PI 428994	375	PI 429045	412	PI 429092	448	PI 429137	484	PI 429176
268	PI 428903	304	PI 428953	340	PI 428996	376	PI 429046	413	PI 429093	449	PI 429138	485	PI 429177
269	PI 428904	305	PI 428954	341	PI 428998	377	PI 429047	414	PI 429094	450	PI 429139	486	PI 429178
270	PI 428905	306	PI 428955	342	PI 428999	378	PI 429048	415	PI 429095	451	PI 429140	487	PI 429179
271	PI 428907	307	PI 428957	343	PI 429000	379	PI 429049	416	PI 429096	452	PI 429141	488	PI 429184
272	PI 428908	308	PI 428958	344	PI 429001	380	PI 429050	417	PI 429097	453	PI 429142	489	PI 429185
273	PI 428909	309	PI 428959	345	PI 429003	381	PI 429051	418	PI 429098	454	PI 429143	490	PI 429186
274	PI 428911	310	PI 428960	346	PI 429004	382	PI 429052	419	PI 429099	455	PI 429144	491	PI 429187
275	PI 428912	311	PI 428961	347	PI 429005	383	PI 429053	420	PI 429100	456	PI 429145	492	PI 429188
276	PI 428913	312	PI 428962	348	PI 429006	384	PI 429054	421	PI 429101	457	PI 429146	493	PI 429189
277	PI 428914	313	PI 428963	349	PI 429007	385	PI 429059	422	PI 429103	458	PI 429147	494	PI 429190
278	PI 428915	314	PI 428964	350	PI 429008	386	PI 429060	423	PI 429104	459	PI 429148	495	PI 429191
279	PI 428916	315	PI 428965	351	PI 429009	387	PI 429063	424	PI 429105	460	PI 429149	496	PI 429192
280	PI 428917	316	PI 428966	352	PI 429010	388	PI 429064	425	PI 429106	461	PI 429150	497	PI 429193
281	PI 428918	317	PI 428967	353	PI 429011	389	PI 429066	426	PI 429107	462	PI 429151	498	PI 429194
282	PI 428919	318	PI 428969	354	PI 429013	390	PI 429067	427	PI 429108	463	PI 429152	499	PI 429195
283	PI 428921	319	PI 428970	355	PI 429015	391	PI 429068	428	PI 429109	464	PI 429153	500	PI 429196
284	PI 428922	320	PI 428971	356	PI 429016	392	PI 429069	429	PI 429110	465	PI 429154	501	PI 429197
285	PI 428923	321	PI 428972	357	PI 429017	393	PI 429071	430	PI 429111	466	PI 429155	502	PI 429198
286	PI 428924	322	PI 428973	358	PI 429018	394	PI 429072	431	PI 429113	467	PI 429156	503	PI 429199
287	PI 428925	323	PI 428974	359	PI 429019	395	PI 429073	432	PI 429114	468	PI 429157	505	PI 429201
288	PI 428927	324	PI 428976	360	PI 429020	396	PI 429074	433	PI 429115	469	PI 429158	506	PI 429202
289	PI 428928	325	PI 428977	361	PI 429023	397	PI 429076	434	PI 429119	470	PI 429159	507	PI 429203
290	PI 428929	326	PI 428979	362	PI 429025	398	PI 429077	435	PI 429120	471	PI 429160	508	PI 429205
291	PI 428934	327	PI 428980	363	PI 429027	400	PI 429080	436	PI 429121	472	PI 429161	509	PI 429206
292	PI 428936	328	PI 428981	364	PI 429028	401	PI 429081	437	PI 429122	473	PI 429162	511	PI 429208
293	PI 428937	329	PI 428982	365	PI 429031	402	PI 429082	438	PI 429123	474	PI 429163	512	PI 429209
294	PI 428938	330	PI 428984	366	PI 429032	403	PI 429083	439	PI 429124	475	PI 429164	513	PI 429210
295	PI 428940	331	PI 428985	367	PI 429033	404	PI 429084	440	PI 429125	476	PI 429165	514	PI 429211
515	PI 429212	552	PI 429250	589	PI 429290	626	PI 519879	662	PI 520448	698	PI 520484	734	PI 542535
516	PI 429213	554	PI 429252	590	PI 429294	627	PI 520122	663	PI 520449	699	PI 520485	735	PI 542536
517	PI 429214	555	PI 429253	591	PI 429295	628	PI 520123	664	PI 520450	700	PI 520486	736	PI 542537
518	PI 429215	556	PI 429254	592	PI 429296	629	PI 520124	665	PI 520451	701	PI 520487	737	PI 542538
519	PI 429216	557	PI 429255	593	PI 429297	630	PI 520255	666	PI 520452	702	PI 520488	738	PI 542539
520	PI 429218	558	PI 429256	594	PI 429298	631	PI 520256	667	PI 520453	703	PI 525197	739	PI 542540
521	PI 429219	559	PI 429258	595	PI 429300	632	PI 520257	668	PI 520454	704	PI 527339	740	PI 542541
522	PI 429220	560	PI 429259	596	PI 429301	633	PI 520419	669	PI 520455	705	PI 527340	741	PI 542542
523	PI 429221	561	PI 429260	597	PI 429302	634	PI 520420	670	PI 520456	706	PI 536647	742	PI 542543
524	PI 429222	562	PI 429261	598	PI 429303	635	PI 520421	671	PI 520457	707	PI 540253	743	PI 542544
525	PI 429223	563	PI 429263	599	PI 429304	636	PI 520422	672	PI 520458	708	PI 542509	744	PI 542545
526	PI 429224	564	PI 429264	600	PI 429306	637	PI 520423	673	PI 520459	709	PI 542510	745	PI 542547
527	PI 429225	565	PI 429265	601	PI 434716	638	PI 520424	674	PI 520460	710	PI 542511	746	PI 542548
528	PI 429226	566	PI 429267	602	PI 434887	639	PI 520425	675	PI 520461	711	PI 542512	747	PI 542549
529	PI 429227	567	PI 429268	603	PI 434888	640	PI 520426	676	PI 520462	712	PI 542513	748	PI 542550
530	PI 429228	568	PI 429269	604	PI 434889	641	PI 520427	677	PI 520463	713	PI 542514	749	PI 542553
531	PI 429229	569	PI 429270	605	PI 434890	642	PI 520428	678	PI 520464	714	PI 542515	750	PI 542555
532	PI 429230	570	PI 429271	606	PI 434891	643	PI 520429	679	PI 520465	715	PI 542516	751	PI 542556
533	PI 429231	571	PI 429272	607	PI 445677	644	PI 520430	680	PI 520466	716	PI 542517	752	PI 542557
534	PI 429232	572	PI 429273	608	PI 445678	645	PI 520431	681	PI 520467	717	PI 542518	753	PI 542558
535	PI 429233	573	PI 429274	609	PI 445679	646	PI 520432	682	PI 520468	718	PI 542519	754	PI 542559
536	PI 429234	574	PI 429275	610	PI 466703	647	PI 520433	683	PI 520469	719	PI 542520	755	PI 542560
537	PI 429235	575	PI 429276	611	PI 476216	648	PI 520434	684	PI 520470	720	PI 542521	756	PI 542562
538	PI 429236	576	PI 429277	612	PI 478305	649	PI 520435	685	PI 520471	721	PI 542522	757	PI 542565
539	PI 429237	577	PI 429278	613	PI 483066	650	PI 520436	686	PI 520472	722	PI 542523	758	PI 542566
541	PI 429239	578	PI 429279	614	PI 491409	651	PI 520437	687	PI 520473	723	PI 542524	759	PI 547164
542	PI 429240	579	PI 429280	615	PI 491549	652	PI 520438	688	PI 520474	724	PI 542525	760	PI 550576
543	PI 429241	580	PI 429281	616	PI 495820	653	PI 520439	689	PI 520475	725	PI 542526	761	PI 552974
544	PI 429242	581	PI 429282	617	PI 495821	654	PI 520440	690	PI 520476	726	PI 542527	762	PI 559372
545	PI 429243	582	PI 429283	618	PI 495869	655	PI 520441	691	PI 520477	727	PI 542528	763	PI 559373
546	PI 429244	583	PI 429284	619	PI 508249	656	PI 520442	692	PI 520478	728	PI 542529	764	PI 561844
547	PI 429245	584	PI 429285	620	PI 511870	657	PI 520443	693	PI 520479	729	PI 542530	765	PI 564431
548	PI 429246	585	PI 429286	621	PI 519232	658	PI 520444	694	PI 520480	730	PI 542531	766	PI 564432
549	PI 429247	586	PI 429287	622	PI 519817	659	PI 520445	695	PI 520481	731	PI 542532	767	PI 564433
550	PI 429248	587	PI 429288	624	PI 519876	660	PI 520446	696	PI 520482	732	PI 542533	768	PI 564434
551	PI 429249	588	PI 429289	625	PI 519877	661	PI 520447	697	PI 520483	733	PI 542534	769	PI 564435

Table 1: (continued 3)

Code	ID	Code	ID
770	PI 564436	806	UC 54
771	PI 564437	807	UC 54
772	PI 564438	808	UC 55
773	PI 564439	810	UC 59
774	PI 564440	811	UC 66
775	PI 564441	812	UC 69
776	PI 564442	813	UC 70
777	PI 564443	814	UC 72
778	PI 591863	815	UC 73
779	PI 591865	816	UC 76
780	PI 591912		
781	PI 591915		
783	Tcl 6437		
784	Tcl 6804		
785	UC 101		
786	UC 102		
787	UC 103		
788	UC 106		
789	UC 108		
790	UC 115		
791	UC 13		
792	UC 15		
793	UC 17		
794	UC 19		
795	UC 20		
796	UC 33		
797	UC 34		
798	UC 38		
799	UC 40		
800	UC 45		
801	UC 46		
802	UC 49		
803	UC 50		
804	UC 51		
805	UC 53		

sand (Carbonatic, Hyperthermic Typic Torripsamment having a negligible level of inherent soil salinity 0.2 dS m^{-1}, [8]) and 2 kg organic compost from cow manure (41% organic matter, 1.64% moisture, pH=7.7, C/N=16.5, 1.5% N, 1.65% K and 1.22% Na, Al Bayadir®, Jabel Ali, Dubai, UAE). One seed per pot was sown around November and irrigation was applied at rates equivalent to ET$_0$ plus 10% for leaching requirements. The experimental plan was randomized complete block with three replicates, where genotypes were randomized within each block. All pots were harvested at maturity and biomass yield (denoted by BY, g/pot), straw yield (denoted by SY, g/pot), spike yield (SPY, g/pot) and grain yield (GY, g/pot) were measured.

In the second step, based on results obtained, only 17% of the collection was grown during 2007/2008 season where the genotypes were grown using three salinity levels 5, 10 and 15 dS m^{-1}. The experimental plan was a split-plot design with three replicates. The main-plot factor was the salinity level and the subplot factor was the genotypes tested.

Field Plot Experiment: In the third step, a small plots field experiment was achieved during 2008/2009 season (third year) on a Carbonatic, Hyperthermic Typic Torripsamment soil (according to the USDA "Soil Taxonomy", USDA-ARS 2005, [8]). This soil was composed of 15% CaCO$_3$ and was a typical desert sandy soil. In addition, the experiment station belongs to arid desertic climate characterized by low rainfall ($\leq$ 150 mm) and high temperatures (mean air temperature equal to 27°C) accompanied by high relative humidity (mean equal to 55%). The annual evaporation rate is equal to ca. 30 times the total amount of annual rainfall. As consequence, dryness is high and extended from April to November. In this experiment, there were 5% high yielding genotypes (selected out of the entire collection) assessed in irrigated field using three salinity levels: 5, 10 and 15 dS m^{-1}, denoted by S1, S2 and S3, respectively. The experimental plan was a split-plot design with three replicates. The main-plot factor was the salinity level and the subplot factor was the genotypes tested. Genotypes were randomized within each main-plot. All plots are laid out in strips. Such designs allow a higher precision for the genotype factor than for the salinity factor.

Prior to planting, the site was harrowed to ensure an even seedbed. Organic compost from cow manure was spread and incorporated at the rate of 10 tons ha^{-1}. Plot measuring 2 m x 4 m, (for a plot area of 8 m^2) were established and seeded manually with a row spacing of 0.5 m to enable manual weeding. An equal number of 200 seeds per entry were used since the germination rate from prior tests did not differ between entries. The plots were sown around mid November to avoid high temperatures and desiccating winds. N-P-K fertilizer (20-20-20%) was applied at a rate of 100 kg ha^{-1} (Growfert Solub™), corresponding to the recommended rate for the region. A drip irrigation system was used with a dripline for each row and an emitter spacing of 0.25 m.

Physiological maturity extended from late April to May. The plots were harvested at maturity to measure yields of biomass (BY) and straw (SY) at 0% moisture. Grain yield (GY) was measured at 15% moisture. Harvest index (HI) was calculated as GY/BY. All yields are expressed in units of tons per hectare.

Statistical Analyses: Statistical analyses were performed in three stages:

- The 801 levels of the genotype factor were genotypes of the entire collection tested during the first growing season 2006/2007 under one salinity level equal to 10 dS m^{-1}. Principal component analyses (PCA) was performed on response variables: straw yield, biomass yield, spike yield and grain yield. PCA helps the selection of nursery at 17% rate of selection for the second cycle selection, based on genotypes loadings on the first and the second components. Note that ‘variate’ stands for any response variable and ‘individual’ stands for any genotype in this analysis. Interpretation of the correlation matrix was guided by the analysis of a plot displaying correlations between each variate to each component in Cartesian diagrams.
- The 134 levels of the genotype factor were genotypes selected out of the entire collection after the first screening cycle for salinity tolerance and that were grown during the 2007/2008 season. Principal component analyses (PCA) was performed on nine response variables: straw yield, biomass yield and grain yield recorded at three salinity levels S1, S2 and S3. PCA helps the selection of nursery at 27% rate of selection for the third cycle selection. Selection procedure was similar to that in stage 1. Selection was achieved using all variates as criteria treated on a hierarchical basis according to end-use ability of the screened genotypes at salinity levels S3 (15 dS m^{-1}), S2 (10 dS m^{-1}) and S1 (5 dS m^{-1}), respectively. As consequence, we proceed as following. Firstly, we selected genotypes having simultaneous high values for both yield: biomass or straw yield and grain yield. These genotypes will serve to dual-purpose end-use. Secondly, we selected genotypes having high grain yield or high forage yield. These genotypes will be able to single purpose end-use. Note that end-use ability of a genotype was determined using its loadings on the two components of PCA and its loading on the variates.
- The 36 levels of the genotype factor were genotypes selected out of the 134 genotypes collection previously screened for salinity tolerance that were grown during the 2008/2009 season. Principal component analyses (PCA) was performed on six response variables: straw yield and grain yield recorded at three salinity levels S1, S2 and S3. Genotype and salinity means were compared using Fisher’s protected LSD test at the $P < 0.05$ level.

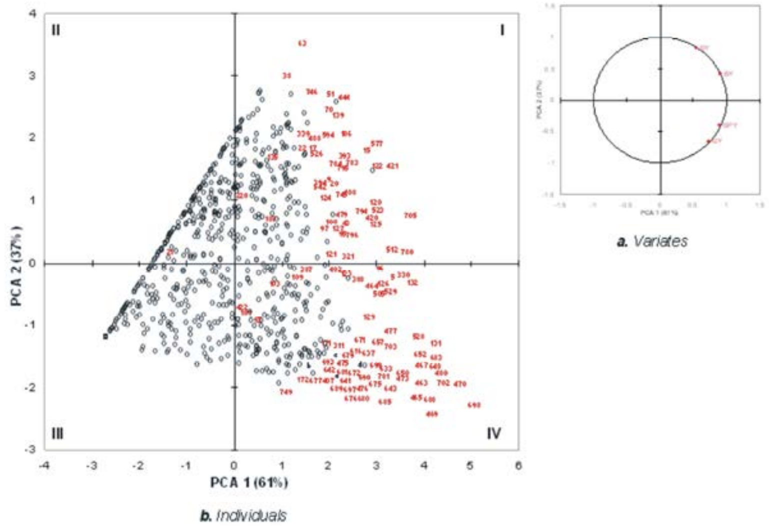
All analyses were performed with SAS Software System Version 6.1 [9] using FACTOR procedure and GLM procedure.

RESULTS AND DISCUSSION

The tolerant and moderately tolerant selected genotypes allow eco-efficient agriculture achieving more production with less input. This type of production encompasses both ecological and economic purpose essential for sustainable agriculture [10]. Moderately tolerant genotypes could be used in moderately saline water environments (1.5–4.5 dS m^{-1}) to obtain reasonable (but not maximum) yields [11-12].

Pot Experiment

First Screening Cycle: For the whole triticale collection grown in field pot during the first growing season, averages of straw yield, spike yield, biomass yield and grain yield were estimated to be equal to 62, 29, 90 and 9.5 g/pot, respectively. The correlation between all these response variables were analyzed using PCA, achieved for 801 triticale genotypes. PCA represented 98% of the variation and clustered the genotypes into significantly different groups according to their abilities to produce forage yield (biomass yield and straw yield) and grain yield (grain yield and spike yield). Note that the loadings of all variates were equal to 1. There were axis 1 (first component), accounting for 61% of the variation. This first component was influenced by biomass yield and spike yield. In contrast, PCA showed axis 2 (second component), accounting for 37% of the variation and influenced by the straw yield and grain yield (Figure 1). Plot of the variates indicates that biomass yield was the highest correlated with straw yield than with grain yield. This result is consistent with previous studies showing differences in triticale growth in various saline root media [13]. Also salinity causes decrease in yield and grain nitrogen yield in various genetic material including doubled haploid and advanced lines [14-15] and in CIMMYT lines collection [16, 7]. PCA showed that as spike yield increase, grain yield increase. Accordingly, intermediate salinity allowed clustering of the collection into different groups according to their end-use purposes: grain production or forage production. Plot of the individuals orders the best yielding with positive coordinates (quadrants I, II and IV) inversely to the low yielding genotypes having negative coordinates for both principal components (quadrants III). On the right side of the PCA, genotypes on the quadrant I have high ability



b. Individuals

a. Variates

Fig 1: Principal component analyses of the variates: straw yield (SY, g/pot), biological yield (BY, g/pot), spike yield (SPYg/pot) and grain yield (GY, g/pot), and the triticale genotypes assessed in field pot experiment during 2006/2007 cropping season under intermediate salinity level equal to 10 dS m-1. Projection of 801 genotypes on two axes: first component (axis 1) and second component (axis 2).
Individuals of the PCA are the genotypes indicated by their corresponding codes (see Table 1).
a, genotypes 169, 466, 471, 678 ; b, genotypes 514, 168, 636, 629; c, genotypes 379, 634, 692, 651, 472; d, genotypes 468, 170, 165, 771, 613, 411.

for forage purpose end-use. In the bottom of the right side of the PCA (quadrant IV) were distinguished the genotypes having highest ability for grain production. Note that variates biomass yield and spike yield were symmetrically opposite for PCA1. As consequence, genotypes localized close to this axis (loadings on PCA lower than 0.5 and higher than -0.5; e.g. 96, 321 and 387) displayed dual purposes end-use ability. These genotypes represented 15% of the selected sub-collection. Triticale international collection showed existence of a high potential for salinity tolerance [16-17]. The genotypes of triticale are the less affected by salinity and sodicity compared to wheat and CIMMYT selected the parents displaying yield reduction lower than 10%. Note that genotype 21 was close to PCA1 but with negative loading showing thus that it displayed weekness for all end-use purposes. Shape of cloud of genotypes showed that straw yield and spike yield seemed to be the most influenced the collection distribution in the PCA. Genotypes belonging to quadrant I and displaying loadings on PCA2 higher than 0.5 were those destined for forage production. In contrast, genotypes belonging to quadrant IV and having loading on PCA2 lower than -0.5 were destined for grain purpose end-use. Indeed, variates SY and GY were symmetrically opposite for PCA1 showing that the collection contained genotypic dimorphism for grain and forage end-use purposes with higher frequency of grain purpose end-use genotypes. Genotype selection was variate-wise and top performing genotypes were the mainly selected. In addition, intermediate performing genotypes showing PCA loadings comprises between 0 and 1 on PCA1 and between -1 and 1 on PCA2 were also subjected to selection but with a much lower selection rate. There was only one genotype 21 having negative loadings on PCA1 that was selected as check for following salinity tolerance screening cycles. Although intermediate salinity level, there were top performing genotypes 51, 421, 698 and 676 for SY, BY, SPY and GY, respectively. Variables recorded for these genotypes were 2.6, 3.4, 2 and 6.2 times higher than average value of the whole collection, respectively. Consequently, potential for grain production of the collection was higher than that for forage production. Accordingly, there were 62% of the sub-collection selected having high grain yield ability.

Second Screening Cycle: The sub-collection composed of 134 genotypes was grown during the second growing season under three salinity levels equal to 5, 10 and 15 dS m^{-1}. At low salinity level, averages grain yield, straw yield and biomass yield were equal to 7, 14 and 27 g/pot, respectively. High salinity level curtailed GY, SY and BY

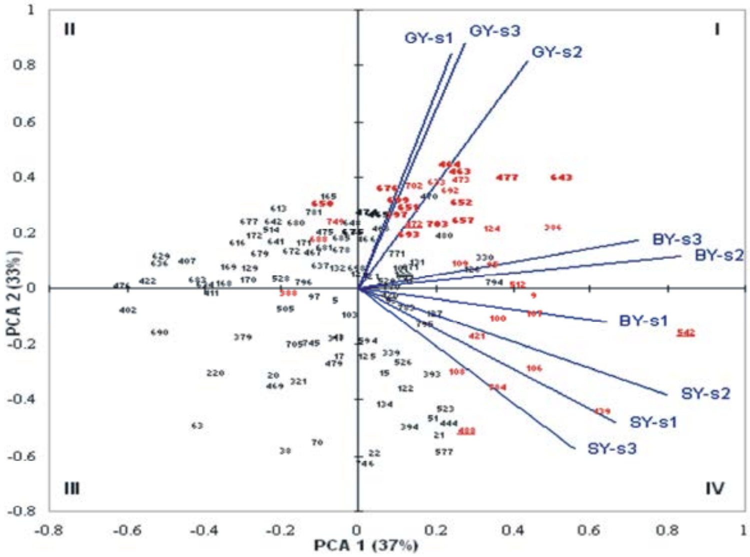


Fig 2: Biplots of principal component analyses of the variates: grain yield (GY, g/pot), biological yield (BY, g/pot), and straw yield (SY, g/pot) with levels indexed by S1, S2 and S3 corresponding to salinity levels of 5 dS m-1, 10 dS m-1 and 15 dS m-1, respectively; and the selected 134 genotypes evaluated during 2007/2008 cropping season in field pot experiment. Projection of 134 genotypes on two axes: first component (PCA 1) and second component (PCA 2) during second and third screening season, respectively.
Solid lines correspond to the variates.
Individuals of the PCA are the genotypes indicated by their corresponding codes (see Table 1).

by 38, 43 and 35 %, respectively and several genotypes displayed values lower than 0, 3 and 8 g/pot, respectively. This result is coherent with the previous findings showing effects of salinity on vegetative growth of triticale and a threshold of ECe=6.1 dS/m [2]. The reported reduction in yield is about 2.5% per a unit dS/m increment. Top performing genotypes at 15 dS m^{-1} displayed 30, 31 and 7% higher GY, SY and BY than averages recorded at 5 dS m^{-1}. Thus potential selection for salinity tolerant was evident and PCA representing 70% of the variation clustered the genotypes into significantly different groups according to their abilities to produce forage contrary to grain. Note that the loadings of all variates were near to 1. There were axis 1 (first component), accounting for 37% of the variation. This first component was influenced by biomass yield and straw yield. In contrast, PCA showed axis 2 (second component), accounting for 33% of the variation and influenced by grain yield (Fig. 2). Biplot indicates that variables recorded at different salinity levels were positively correlated, showing that genotype ranking did not highly differ between the salinity levels. As consequence, proportion of widely adapted genotypes was high in this sub-collection. Accordingly, all salinity levels allowed simultaneously clustering of the collection into different groups according to their end-use purposes: grain production or forage production. Biplots orders the best yielding with positive coordinates (quadrants I, II and IV) inversely to the low yielding genotypes having negative coordinates for both principal components (quadrants III). Note that genotype 388 was close to PCA1 but with negative loading, even on PCA2, showing thus that it displayed weakness for all end-use purposes. Shape of cloud of genotypes showed that grain yield and straw yield seemed to be the most influenced the collection distribution in the PCA. Genotypes belonging to quadrant I and displaying loadings on PCA2 higher than 0.2 were those destined for grain production. In contrast, genotypes belonging to quadrant IV and having loading on PCA2 lower than -0.2 were destined for forage purpose end-use. Genotypes belonging to quadrants I and IV and displaying loadings on PCA2 comprises between -0.2 and +0.2 were destined for dual end-use purpose. These genotypes represented 23% of the selected sub-collection. Genotype selection was variate-wise and top performing genotypes were the mainly selected.

There was only one genotype 388 having negative loadings on PCA1 and PCA2 that was selected as check for following salinity tolerance screening cycles.

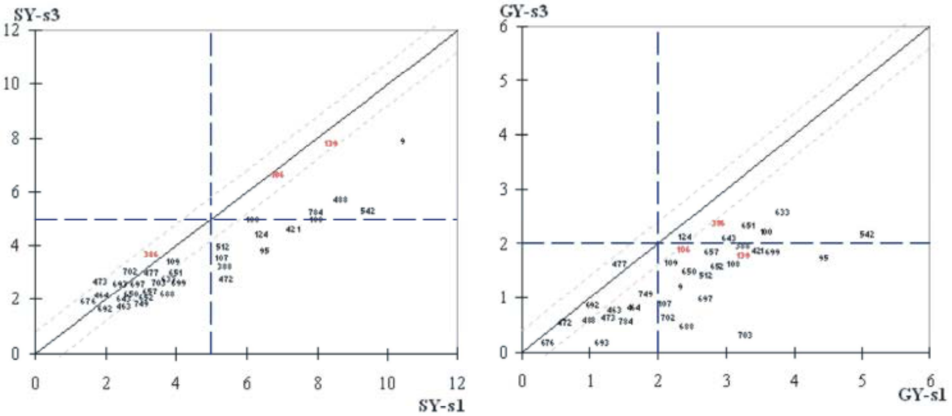


Fig 3: Comparison between straw yield (SY, t ha-1) and grain yield (GY, t ha-1) recorded under salinity levels S1=5 dS m-1and S3=15 dS m-1 for 36 selected genotypes grown in field experiment during 2008/2009 growing season.
Solid lines correspond to the situation of equality between two salinity levels.
Dotted lines correspond to mean standard errors of the contrasts of the average difference between two given salinity levels.
Solid dotted lines correspond to target values of straw yield and grain yield as defined by the selection procedure.
Numbers corresponds to genotypes' codes (see Table 1)..

Whatever salinity level, there were top performing genotypes 464, 643 and 139 for GY, BY and SY, respectively. Variables recorded for these genotypes were 1.4, 1.3 and 1.07 times higher than average value of the whole collection at low salinity level, respectively. Consequently, potential for grain production of the collection was higher than that for forage production. There were 62% of the sub-collection selected having high grain yield ability.

Field Experiment: In the present conditions yield potential was intermediate with target grain yield equal to 2 t ha^{-1} and target straw yield equal to 5 t ha^{-1}. Genotypes differed for grain yield and straw yield for all salinity levels (Fig. 3). Salinity level equal to 15 dS m^{-1} was highly discriminating the genotypes assessed for grain and forage yield. Indeed, 55 to 30% of the collection did not reach target values of straw and grain yields, respectively. Inter-genotypic variation was the highest for grain yield compared to straw yield. Indeed, grain yield varied from 0.3 to 5 t ha^{-1} and from 0.2 to 2.5 t ha^{-1} at low and at high salinity levels, respectively. At low salinity level, 71% of the collection released the target value whereas less than 20% of the collection released the target at high salinity level. The later cited part of the collection was composed of genotypes specifically adapted to unfavorable environments. In contrast, genotypes showing grain yield higher than target only at low salinity level were specifically adapted to favorable environments. Besides, genotypes 542 and 100 displayed simultaneous forage and grain purpose end-use at high salinity level. At low salinity level, straw yield varied the highest between 1.7 and 10.5 t ha^{-1}. However, variation recorded at high salinity level was from 1.7 to 8 t ha^{-1}. Target straw yield was obtained by 42% of the collection at low salinity level. In contrast, only 22% of the collection displayed straw yield higher than the target at high salinity level. The later cited genotypes were consequently specifically adapted for forage production under high salinity level. Genotypes 139 and 106 displaying straw yield higher than target whatever salinity level and showing low yield reduction due to salinity were the most forage genotypes adapted to salinity stress. In contrast genotypes 472 and 388 showed straw yield higher than target only at low salinity level and yield reduction due to salinity stress was higher than 50% testifying thus for their specific adaptation to favorable environments. Genotypes localized on the first bisector displayed performances not differing for different intensity of salinity stress, were consequently considered as stable genotypes. Stable genotypes displaying yields higher than targets were the most interesting because of their wide adaptation. In contrast, those that were stable but low yielding, particularly genotype 676 showing weakness for both forages and grain yields, were less interesting.

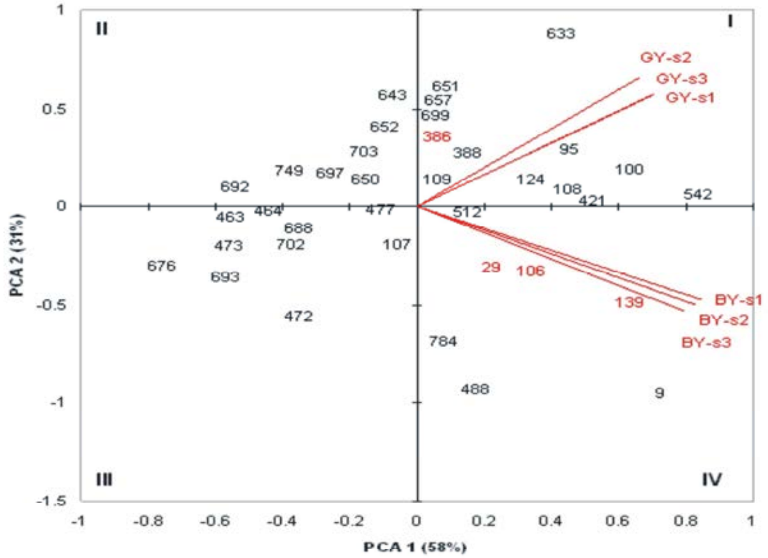


Fig 4: Biplots of principal component analyses of the variates: grain yield (GY, t ha-1) and straw yield (BY, t ha-1 with levels indexed by S1, S2 and S3 corresponding to salinity levels of 5 dS m-1, 10 dS m-1 and 15 dS m-1, respectively; and the 36 selected genotypes evaluated during 2008/2009 cropping season in field experiment. Projection of 36 genotypes on two axes: first component (PCA 1) and second component (PCA 2) during second and third screening season, respectively.

Numbers corresponds to genotypes' codes (see Table 1)..

Genotype ranking variation argues for a high selection pressure applied in the present experiment. Grain yield and straw yield were also recorded at intermediate salinity level. The correlations between all these response variables were analyzed using PCA for 36 triticale genotypes. PCA represented 89% of the variation and clustered the genotypes into significantly different groups according to their abilities to produce forage yield (straw yield) and grain yield. Note that the loadings of all variates were equal to 1. Biplot orders the best yielding genotypes with positive coordinates (quadrants I, II and IV) inversely to the low yielding genotypes having negative coordinates for both principal components (quadrants III, 30% of the collection). Genotypes on quadrant I have high ability for grain purpose end-use. In quadrant IV were distinguished the genotypes having highest ability for forage production. Genotypes localized close to PCA1 (loadings lower than 0.5; e.g. genotypes 421 and 542) displayed dual purposes end-use. High levels of salinity tolerance in triticale are consistent with several research findings that showed an evident comparative advantage to wheat and a similar level of salinity tolerance to barley [18-20]. Many promising lines are actually identified among international collections of CIMMYT and also many national breeding programs [21-22]. At ICBA, we selected tolerant triticale genotypes and we also identified negative controls such as genotype 676 that displayed weakness for all end-use purposes.

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