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Full Length Research Paper

Highly client-oriented breeding with farmer participation in the Ethiopian cereal tef [*Eragrostis tef* (Zucc.) Trotter]

Getachew Belay*, Hailu Tefera, Anteneh Getachew, Kebebew Assefa and Gizaw Metaferia

Ethiopian Institute of Agricultural Research, Debre Zeit Centre, P.O. Box 32, Debre Zeit, Ethiopia.

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This paper describes a highly client- oriented breeding applied to enhance the development and release of a tef (*Eragrostis tef*) variety with farmer participation in Ethiopia. The main features include; clear objective, target cross, early-stage researcher selection, multi-location yield trial, farmer on-station selection, judicious selection of few candidate varieties based on farmers' and researchers' selections, farmer managed on-farm trials, and release through the existing formal procedure. In the application of this strategy, tef exemplifies a crop with local importance, a clear market-driven selection criterion (cash crop) and farmers have better judgment of the criterion than researchers. Using farmers' consistent selection of genotypes, in conjunction with the required quantifiable data, breeders were able to release a new tef variety named "*Quncho*". The new variety was not the highest yielder, but it was higher in grain yield and better in seed-color quality (very white seed- color) than the long-time cultivated variety DZ-01-196 (*Magna*), which was used as quality check. Given the appropriate degree of client-orientation, the results also show how farmer participation and formal breeding programs complement each other so as to overcome the rather prohibitive variety release procedures based on data from participatory breeding alone.

Key words: Highly client-oriented breeding, *Eragrostis tef*, Ethiopia, participatory breeding, tef variety.

INTRODUCTION

Critique of formal research methods for failure to produce appropriate technologies for resource-poor farmers, and "inappropriate" (not participatory/centralized) institutional structure of agricultural research has led to the initiation and developments of Farmers Participatory Research (FPR) approaches (Martin and Sherington, 1997). Participatory Variety Selection (PVS) and Participatory Plant Breeding (PPB) are applications of FPR in variety development and dissemination activities (Witcombe et al., 1999; Virk et al., 2003). Despite its success, PPB has not been without its controversies, misapplications, confusions, and limitations, particularly in contradistinction to the so-called formal (conventional) breeding (Bantley, 1994; Tripp, 2002; Witcombe et al., 2005). Recently, Witcombe et al. (2005) proposed the removal of dualism between PPB and non-participatory (formal) breeding programs by calling the former "*highly client-oriented plant breeding*"; the indicators are orientation to markets and clients (product design), and orienting germplasm, selection environments and variety testing towards farmers in the target market. Apparently, there cannot be "one-size-fits-all" model, and modifications are expected in different crops grown in different environmental and socioeconomic setups.

Tef [*Eragrostis tef* (Zucc.) Trotter] is the most important indigenous cereal of Ethiopia. Tef straw is equally important to farmers to feed their animals. Its production area is increasing at unprecedented scale due to increased market-demand (both local and foreign) . The germplasm base of tef limits spectacular jump in its yielding ability. However, because of the facts that tef is culturally deep entrenched in the food-habit of the Ethiopian population, it is mainly a cash crop, it covers more than two million hectares of land, and Ethiopia has long been in food-

*Corresponding author. E-mail: tef -res@ethionet.et . Tel: +251-11-4331187. Fax: 251-11-4338061

deficit, the "little" tef-yield increment contributes in the strive towards food security (Tefera and Belay, 2006).

Variety development in the formal tef breeding has until recently been based on grain yield and crop cycle (maturity group). Under this traditional linear approach, large numbers of breeding lines are developed at research stations and their performance evaluated, largely on the basis of grain yield, through observation nurseries and various levels of multi- location tests. A few varieties are then identified, verified and officially approved for release (Tefera et al., 2001). This approach has impeded the speed of variety dissemination, particularly in central Ethiopia where farmers have access to the biggest terminal tef-market in the capital city, Addis Ababa. Now that market- oriented agricultural research and production is the policy of the Ethiopian government, there are openings where farmers can participate in aid of the selection process through highly client-oriented breeding (Witcombe et al., 2005).

The National Tef Research Project has been testing the suitability of participatory approaches in its breeding activities, since 2000. In our PVS work, we identified that seed color, driven by market forces, is the overriding selection criteria of tef varieties by farmers in two of the major tef growing *woredas* (= district) of Ethiopia, Ada and Akaki (Belay et al., 2006). In the present work, we describe a highly client- oriented breeding applied to enhance the development and release of a new tef variety with farmer participation. The results and lessons from tef are discussed in light of the suitability and timing of farmer participation, and compatibility with the formal variety release procedures in Ethiopia.

MATERIALS AND METHODS

Objective setting, 'target cross' and development of homozygous lines

DZ-01-196, the most popular variety for its seed-color quality but low-yielder one, was crossed with two parental varieties/lines in 2000. However, only the cross, hereafter referred to as 'target cross', between DZ-01-974 x DZ-01-196 proceeded further, for it supplied more promising derivatives than the other crosses (selection among crosses). DZ-01-196 and DZ-01-974 were developed through pure-line selection from farmers' cultivars and were released in 1970 and 1995, respectively (Tefera et al., 2001). Even though several higher-yielding tef varieties, including DZ- 01-974, have been released (Hundera, 1998; Tefera et al., 2001), DZ-01-196 is still the best-preferred one to grow by farmers in the study areas (Ada and Akaki *woredas*) because of its seed quality. DZ-01-974, in addition to its high yield and wide adaptation, has a relatively good plant stature and strong culm. The target cross was, therefore, aimed at developing a tef variety that is equal or better in grain quality, but higher in grain yield than DZ-01-196.

About 500 F_2 -derived F_3, F_4 and F_5 generations were raised in the glasshouse of the Debre Zeit Agricultural Research Center (DZARC) using single-seed-descent method in 2000 and 2001. During the 2001 main season (July - December), 500 recombinant inbred lines (RILs) of the F_6 generation (homozygous lines) were evaluated in a single row of 1 m length, spaced 50 cm apart. From the 500 RILs, 18 RILs were selected based on seed color, grain yield and uniformity; these were planted in the 2002 off-season (February to May) to further check their phenotypic characteristics and increase their seed. After a one-year test in the 2002 main season pre-national variety trial, 10 RILs were promoted to the on-station national variety trial (NVT). DZ-01-196 was always grown together to aid selection for seed color by researchers.

On-station national variety trials (NVT)

Sixteen tef genotypes together with the two parental varieties (DZ-01-974 and DZ-01-196), a standard check (DZ-01-1285 or Koye) and a local check were assembled in the National Variety Trial (NVT). The genotypes were evaluated at seven test locations (Adet, Akaki, Debre Zeit Light Soil, Debre Zeit Black Soil, Denbi, Minjar and Ginchi) of the national tef research project for two years (2003 and 2004). Among the 16 test genotypes, seven were pure-line landrace selections; the remaining 10 genotypes were selections from the target cross. DZ-01-196 was also used here as seed-quality check. The design used was randomized complete block with four replications on standard plots (2 x 2 m). Agronomic practices were applied as per the research recommendations specific to the locations. In Ethiopia, minimum data from six environments (two years and three locations) are required for a candidate variety to be considered for evaluation by the National Variety Release Committee (NVRC). Data were collected on grain yield (GY), shoot biomass (SB), days to panicle emergence (PE) and panicle length (PL).

Farmers' selection from on-station trials

Details of the study area (Akaki and Ada *woredas* of the Ethiopian central highlands) and farmers' research groups are given elsewhere (Belay et al., 2006). Briefly, 41 farmers from the two *woredas* and selected from four and five peasant associations (PAs), respectively, from Akaki and Ada, participated in the selection. Farmers' on-station evaluation and selection was carried out on the first-year (2003) on-station trial of the NVT at Akaki and Debre Zeit experimental stations. Farmers evaluated the varieties during the first and last weeks of November at Debre Zeit and Akaki, respectively. At these times, the crop was close to maturity; farmers insisted that it would be difficult for them to select unless they see grain characteristics on the spot, despite the fact that seeds of each test genotype from previous harvests were displayed together. Farmers' selection followed two steps; first they were grouped in their PAs to conduct the selection, then they were re-grouped at *woreda* level to discuss and reach to a consensus. Researchers only explained farmers the objectives of the trial and their participation, and provided information to farmers' queries.

Farmers' on-farm testing

Seeds of six farmer-selected genotypes from on- station selection were multiplied during the off-season of 2004. In Ethiopia, in one season, the National Variety Release Committee (NVRC) regulations allow a maximum of three candidate varieties for evaluation from a given crop. Therefore, in order to reduce the number of farmer- selected genotypes for application to NVRC, and for the on-farm test as well, 10 volunteer farmers (selected from the 41 members of the farmers' research group) were presented with seeds of the six genotypes they selected earlier for re-selection. At this stage, on the basis of farmers' impression for seed-colour, and after evaluating the entire data from NVT (2003 and 2004), researchers identified three candidate varieties for evaluation by the NVRC. The three candidate varieties together with farmers' varieties as check were grown and evaluated by farmers in 2005.

Farmers were persuaded to use their best seed-colour cultivar to

Table 1. Farmer selected genotypes (out of 16 tested) in tef National Variety Trial (on-station trial) at Akaki and Ada *woredas*, Ethiopia, 2003.

Code #	Genotype	Selected at
8	DZ-01-2906	Akaki
14	(974 x 196) RIL-45	Debre Zeit (Ada)
15	(974 x 196) RIL -95	Akaki
16	(974 x 196) RIL-152	Akaki, Debre Zeit (Ada)
19	(974 x 196) RIL-355	Akaki, Debre Zeit (Ada)
20	(974 x 196) RIL-427	Akaki

include as check. Each genotype was planted in a 10 m x 10 m plot, side by side. Farmers carried out all farm management prac-tices; researchers collected quantitative data on agronomic traits similar to those in the NVT. Farmers also conducted preference ranking of the candidate varieties for their important selection traits, which they identified previously (Belay et al., 2006). Ranks of 1 to 4, in diminishing trend, were used. Researchers provided the evalua-tion formats, which were filled by farmers.

Statistical analyses

National variety trial: Quantitative data were subjected to analy-ses of variance (ANOVA) at individual locations, years, and combi-ned over locations and years. Homogeneity of error variances for each trait was checked for the combined ANOVA.

On-farm trials: Quantitative data collected by researchers from the on-farm trials were also subjected to a randomized complete block ANOVA, using farmers as replicates. The non-parametric statistics, Kruskal-Wallice test (Steel and Torrie, 1980) was employed to test the significance of the farmers' preference rankings; the null hypo-thesis was that there are no differences among individual genoty-pes for the farmers' selection criterion used for tef.

Genotype x environment interaction (g x e): Joint-regression analysis for grain yield was carried out in order to determine the magnitude of g x e following Eberhart and Russell (1964). Data from 14 environments (7 locations and 2 years) on the 20 genoty-pes in the NVT were used. All statistical computations were carried out using the Agrobase software package (AGROBASE™ , 2004).

RESULTS

Farmers' on-station selection

All the activities from crossing to assembly of genotypes in the 2003-04 NVT followed the formal tef breeding procedure. However, because the promise of the 'target cross' for seed-color quality was quite evident starting from the F_4 generation, we skipped two evaluation steps (two years) often run in the formal breeding (observation nursery and preliminary yield trial).

Similar to our participatory variety selection, market value (very white-seed colour) was the overriding selec-tion criteria for farmers (Belay et al., 2006). Farmers at Akaki and Ada, selected six genotypes; two of them were common to both locations (Table 1). Among the seven pure-line landraces, farmers selected only one; the rest (five genotypes) were derivatives from the target cross. During group discussion, farmers agreed on the superior-rity in seed quality of the six genotypes they selected to DZ -01-196 (quality check) that they have been cultivating for more than 30 years.

Performance evaluation of NVT (Researcher evaluation)

Mean grain yield data of the six farmer-selected genoty-pes, together with the parental varieties, are given in Table 2. In the first-season NVT (2003), significant ($p < 0.05$) differences among the test genotypes were obser-ved. All farmer-selected genotypes gave higher yields than both parents. In the second season (2004), all of them yielded higher than the quality check (DZ-01-196) but lower than the high-yielding parent (DZ-01-974) . In the combined analysis across locations and years, all far-mer-selected genotypes were higher yielding than the quality check, but only three of them (codes#15, 19 and 20) gave higher yields than DZ-01-974. The contribution of the genotype - environment interaction (g x e) variance to the total variance was less than five percent, and the linear response of g x e was non-significant (data not shown).

Identification of candidate varieties for NVRC evaluation and for on-farm trials

Seed re-evaluation by the 10 farmers of the genotypes selected from the on-station NVT gave the following result: Four farmers re-selected RIL-355; three farmers re-selected RIL-152; DZ-01-2906 and RIL-427 were not reselected (Table 2) . Researchers decided to present two lines (RILs 152 and 355) as candidate varieties for official evaluation, based on a compromise between farmers' selection and grain-yield performance (researcher evaluation) in the NVT (Table 2). RIL-152 was not a good performer but was selected by farmers at both Akaki and Ada (2003), and re-selected for its seed by three farmers. RIL-355 was selected because farmers at both *woredas* selected it, it performed well in the on-station NVT, and the highest number of farmers re-selected it for its seed

Table 2. Mean grain yields of the six farmer-selected genotypes from National Variety Trial, together with the parental check varieties, grown at eight locations in Ethiopia, 2003 and 2004.

Code#	Variety/genotype	Grain yield (kg ha^{-1}) (2003)	Rank	No. of farmers who re-selected*	Grain yield (kg ha^{-1}) (2004)	Rank	Grain yield (kg ha^{-1}) (Combined)	Rank
01	DZ-01-974 (check)	2294	17	-	2612	1	2453	8
02	DZ-01-196 (check)	2190	19	-	2241	20	2216	19
08	DZ-01-2906	2336	12	0	2432	13	2384	15
14	(196 x 974) RIL-45	2338	11	2	2432	12	2385	13
15	(196 x 974) RIL-95	2534	3	1	2521	6	2527	3
16	(196 x 974) RIL-152	2364	10	3	2382	16	2373	16
19	(196 x 974) RIL-355	2498	4	4	2424	14	2461	6
20	(196 x 974) RIL-427	2601	1	0	2477	10	2539	2
	Mean	2365			2455		2410	
	LSD (0.05).	222.2			202.6		145.7	
	CV (%)	16.9			15.7		16.3	

* Out of the 10 farmers who made re-selection for seed color quality

Table 3. Mean performances of three candidate tef varieties grown under on-farm (F) and on-station (S) trials, Ethiopia, 2005.

Variety	GY (kg ha^{-1})		SB (t ha^{-1})		Traits† PE (days)		Pht (cm)		PL (cm)	
	F	S	F	S	F	S	F	S	F	S
RIL152	1360	2527	6.41	10.89	45.4	49.3	89.4	93.6	31.2	35.6
RIL427	1374	2539	6.18	10.94	44.6	48.3	89.3	92.0	32.2	36.0
RIL-355	1271	2461	6.91	11.84	45.9	51.3	92.6	95.9	34.4	37.4
Farmers' variety	1188	2254	6.18	10.09	44.7	44.6	89.2	86.6	32.1	33.4
Mean	1298	2410	6.42	10.72	45.2	48.1	90.1	91.3	32.5	35.5
LSD (0.05)	131.3	145.7	457.8	ns	ns	ns	ns	ns	ns	ns
CV (%)	11.0	16.3	7.8	14.3	2.5	3.3	5.3	7.6	9.0	10.0
F/S (%)	53.9		59.9		94.0		98.7		91.5	

†GY= grain yield, SB = shoot biomass, PE = days to panicle emergence, Pht = plant height, PL = panicle length.

quality. RIL- 427 was also included for contrasting reasons; it was selected only at one *woreda* (Ada) and not re-selected for its seed, but showed best performance (among the target cross derivatives) in the NVTs. NVRC evaluated the three candidate varieties in 2005. On-farm data or farmers' preference ranking was not presented to NVRC; however, the technical committee consulted farmers' view on the candidate varieties during its verification trials. Finally, RIL-355 was approved for official release in March 2006 under the variety name '*Quncho*'.

On-farm trials and farmers' preference ranking

In the on-farm trials, significant differences among the test genotypes were observed only for grain and shoot-biomass yields (Table 3). Farmers' preference rankings for various selection traits of tef (Belay et al., 2006) are presented in Table 4. Kruskal-Wallis test showed that significant genotype differences ($p<0.05$) exist due to farmers' perception for most of the traits, except for leaf rust resistance, maturity, seed yield and tolerance to cold winds. RIL-355 ranked first in average ranking for all traits except seed yield and tolerance to cold winds for which it was second to RIL-152. RIL-355 was thus the best preferred in the overall ranking and farmers' general assessments (eye judgment). Though we did not focus on straw yield, farmers recognized the high biomass yield of RIL-355, and this is in agreement with the experimental results (Table 3).

On-farm mean grain and biomass yields were only 54% and 60%, respectively, of the on-station trials for the corresponding genotypes; the differences for the other yield-related traits were minor (Table 3). All the candidate varieties gave higher mean grain yields than the farmers' cultivars; RIL-427 was the highest yielder, and the farmers' cultivar (local check) was the lowest yielder at both the on-station and on-farm trials.

Table 4. Farmers' (n = 10) average preference ranking (1 best preferred to 4 least preferred) of the three candidate varieties and farmers' cultivar (check) in tef on-farm trials, Ethiopia, 2005.

Selection criteria	RIL152	RIL427	RIL-355	Farmers' cultivar	Kruskal-Wallis test (*p*-value)
Leaf rust resistance	1.9 (4)	2.4 (2)	2.3 (4)	3.2 (1)	0.0733
Maturity	3.1 (1)	2.1 (2)	2.0 (4)	2.8 (3)	0.0818
Panicle length/weight	2.6 (0)	3.0 (0)	1.4 (8)	3.0 (2)	0.0038
Plant height	2.9 (0)	2.8 (1)	1.3 (8)	3.0 (1)	0.0017
Seed color	2.3 (2)	3.1 (2)	1.7 (4)	2.9 (2)	0.0249
Seed size	3.0 (1)	3.2 (0)	1.9 (4)	1.9 (5)	0.0098
Seed yield	2.1 (4)	2.5 (2)	2.2 (3)	3.2 (1)	0.1232
Stiff straw/lodging resistance	2.4 (2)	2.5 (1)	1.7 (6)	3.4 (1)	0.0098
Tillering capacity	2.0 (3)	2.5 (2)	1.8 (5)	3.7 (0)	0.0007
Tolerance to cold wind	2.0 (4)	3.1 (0)	2.2 (5)	2.7 (1)	0.1232
Overall average	2.5	2.8	1.8	3.0	-
General‡	2.0 (3)	2.6 (1)	1.7 (6)	3.7 (0)	0.0004

† Numbers in parenthesis are the number of times each variety was ranked "1". ‡ Farmers' general assessment (eye judgment).

DISCUSSION

Clear objective, appropriate parental choice, and focused selection were the main inputs in the present work from breeders. For tef, the reason for focusing on one cross but evaluating large numbers of segregating populations and homozygous lines has its peculiar reasons; the tef crossing technique is too tedious and the hybrids and subsequent generations require extra care and resources to handle (the tiny seed size of tef makes it prone to an easy mixture as a single plant produces a colossal number of seeds). This is analogous to what Witcombe and Virk (2001) described "the low-cross-number and careful choice of parents" breeding strategy for self-pollinated crops, and applied it for rice (Virk et al., 2003).

The number of farmer-selected genotypes from the on-station NVT may seem limited, but this is because resea-rchers, in addition to the quantifiable traits, have already exerted selection pressure for a criterion used by farmers (very white seed-color) and thereby narrowing the scope of the selection. However, the facts that, despite using similar selection criteria, only two genotypes were commonly selected at the two *woredas* and, the absence of significant g x e interaction for grain yield that included test locations even wider than Akaki and Ada *woredas*, indicates that cryptic (to quantify) features of specific adaptation may be important.

Given that researchers are well aware of the farmers' selection criteria, the results of the present work lend credence to previous suggestions by Thiele et al. (1997), and Morris and Bellon (2003) that involving farmers later in the selection process is sufficient. When the farmers' criterion is just one factor, seed-color in the case of tef, we predict that the need for farmer involvement might diminish. In the bigger picture, when farmers' selection criteria are strongly influenced by market demand, temporal and spatial effects have little bearing except adaptation. Therefore, researchers/breeders are less challenged in bringing a mix of complex traits into a single variety; what is simply required is increased knowledge by researchers of farmers' selection criteria (Thiele et al., 1997), which, according to Witcombe et al. (2005), means an "appropriate degree of client-orientation".

Farmers' choices were consistent across the first-year on-station selection, the second time seed re-selection through to the on-farm preference rankings. Farmers were not in favor of RIL-427, despite its higher average yield. For tef farmers in the study areas, all other traits are considered only after seed-color is met (Belay et al., 2006). The fact that farmers have detected the seed-color differences quite early explains why they have preferred RIL- 355, despite its relatively lower grain yield than RILs 427 and 152. Kitch et al. (1998) have shown that, above a certain minimum yield, the acceptability of a variety is determined by factors other than grain yield. On the other hand, farmers did not perceive significant different-ces for grain yield among the three candidate varieties and their own cultivars, which was not in agreement with the experimental data; up to 13.5% yield advantage was observed between the highest yielding RIL-427 (1374 kg ha^{-1}) and the lowest yielding 'farmers' cultivar' (1188 kg ha^{-1}) (Table 4). By any standards, a 13.5% yield advantage is quite high, but the fact that it could not be discernible to far-mers warrants that, be it from on-station or on-farm trials, tef grain yield is better quantified and analyzed by resea-rchers.

The remarkable agreement between the overall rankings, farmers' general assessment and the decision of the NVRC to approve RIL-355 (Quncho) for official release, provides supportive evidence that farmer participation could be accommodated within the existing institutional breeding schemes and variety release procedures. This is as opposed to calls for policy changes of variety release procedures in order to accommodate the less quantifiable PPB data (Joshi and Witcombe, 2002; Morris and Bellon, 2003). In Ethiopia, given that regulations disallow seed multiplication and dissemination of unapproved varieties of any crop, except in emergency relief, what is to change may be not all crops necessarily need to pass through the formal variety release system, regardless of the type of breeding program. Suffice is relieving relatively less important and indigenous crops, localized in marginal environments, from the stringent regulations so as to encourage the participation of Non-Governmental Organizations and other projects involved in variety development and seed dissemination. Good agreements between farmer and researcher selection were documented in rice (Virk et al., 2003).

The grain-yield gap between on-station and farmer-managed, on-farm trials, however expected, are very wide. Use of inputs does not explain it since fertilizer application rates were similar and no other external inputs were used in both cases. It is possible that two factors might have played a role; nutrient accumulation, particularly phosphorous, in research-station fields have rendered fertility advantage, and the large plot size (400 m^2 per farmer excluding the alleys) might have been a cause for farmers to pay lesser attention, particularly weeding, than on-station fields. In any case, such a huge gap on the one hand indicates that, being a cash crop, tef productivity can be increased to a considerable extent through the improvement of management practices alone. On the other hand, the gap shows that on-station trials may not represent the target environment of farmers' fields. That means, recommendations based on higher yields of on-station trials could lead to inappropriate varieties that may not necessarily grow well in farmers' fields. Therefore, because the possibility of changing farmers' field conditions is remote, tef multi-location yield tests may need to consider the use of data generated from on-farm trials as well. In pearl millet (*Pennicetum glaucum* L. Br.), Baidu-Forson (1997) has noted that differences between on-station and on-farm performances of varieties are likely to be observed in only grain and biomass yields, which is in agreement with the present results.

In conclusion, the present work is not the traditional linear approach since farmers have participated in the on-station selection and have conducted their own on- farm testing. On the other hand, because few genotypes (because of fixed farmers' selection criteria) were tested on-farm and farmers were not allowed to continue with seed multiplication of their choice (regulations disallow prior to the approval by NVRC), it might not be considered as PPB *per se*. That means as a cash crop and when grown in areas of relatively optimum environmental conditions, tef may not exactly fit into PPB, but farmer participation is very much helpful. This has prompted formal breeders to select for very white seed color, which was not practiced before. As pointed out by Chianu et al. (2006), the two-way feed back between farmers and researchers is indeed vital component of highly client-oriented breeding programs in locally important and traditionally cultivated cash crops like tef in Ethiopia.

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