International Journal of Agriculture Innovations and Research
Volume 12, Issue 4, ISSN (Online) 2319-1473
Manuscript Processing Details (dd/mm/yyyy):
Received: 09/01/2024 | Accepted on: 02/02/2024 | Published: 19/02/2024

Traits in Major Crops Requested by Farmers: Focus on Pearl Millet in West Africa's Climate Gradient

Hannatou O. Moussa[1*], Charles I. Nwankwo[2], Ali M. Aminou[3] and Ludger Herrmann[4]
[1]National Institute of Agricultural Research of Niger, Department of Rainfed Crops (DCP), Niger.
[2]University of Hohenheim, Institute of Soil Science and Land Evaluation, Emil-Wolff Str. 12a, 70599 Stuttgart, Germany.
[3,4]Federation of Maradi Farmers' Unions, FUMA Gaskiya, Niger.
*Corresponding author email id: hannemoussa@yahoo.com

***Abstract* – In semi-arid West Africa, enhancing crop yields in a sustainable manner is complex. This is partly related to harsh climatic conditions and wrong assumptions of plant breeders and developers in the context of what farmers really need. In the integrated research and development project in West Africa (CODE-WA), covering an agroecological gradient with sites from 400 -1100 mm annual rainfall in Niger, Mali, Burkina Faso and Ghana, a dual approach was followed to determine farmer-requested traits for major crops with emphasis on pearl millet. Researcher-managed multi-location trials were conducted at all sites over three seasons (2008-10). In parallel the Opposite Pyramid Approach was developed and applied to allow farmers base varietal selection based on their needs. Field testing and interview results on farmer-preferred traits are presented here. Conclusions were drawn for adapted breeding strategies under the climate variability paradigm. Under extreme environmental conditions as given in the Sahel, considering farmers' views, local strategies and adaptation potential are mandatory. According to agroecological zones, different breeding objectives need to be set.**

***Keywords* – G x E Trials, Farmers' Preference, Short Duration Varieties, Opposite Pyramid Approach.**

I. Introduction

The semi-arid areas of West Africa are prone to climate variability [1]. Apart from decadal fluctuations as expressed by the droughts of the 1970 to early 1980 [2], inter-annual variability is a real obstacle to agricultural development [3]. This is coupled with intra-seasonal droughts occurrence, which is foreseen to exacerbate due to climate change [4]. Hence, a call for action to improve the adaptation capacity of local and subsistence-oriented farmers in the West African Semi-Arid Tropics (WASAT) is crucial.

One potential option to better deal with climate variability is to increase agro-phytodiversity at the farm and village level. This will make a diversity of potentially adapted crop species and different varieties of a popular crop species available, and more options to farmers for their tactical decisions [5]. E.g., if farmers have access to crop varieties with different life cycles, they can adapt via a tactical crop or cultivar choice, to the length of the growing season as indicated by the onset of the rainy season. Alternatively, they will not be dependent on the rainy season staple crops if they have the possibility for off-season gardening activities. They will most likely take a higher risk to experiment with new options. However, development work during the last decade has shown that WASAT farmers are in general at adverse risks [6]. These new options hypothetically pose great challenges.

Consequently, these options need to be tailored and tested together through a participatory approach [7]. In the frame of the CODE-WA R4D (Research for Development) project, several crops as well as varietal options were tested in a dual approach, combining researcher-managed multi-location trials with on-farm testing against local varieties in a three years' time period i.e., 2008 - 10. Taking pearl millet (*Pennisetum glaucum* (L.) R.Br.), the most important Sahelian staple food crop as an example, it shows (i) which traits are important to farmers facing climatic variability (ii) which factors influence their decision, and (iii) how these decisions correlate with the measures in the researcher-managed trials. This paper discusses what the organizers of breeding programs in West Africa could learn from the local farmers.

II. Methodology: Approach and Methods

1.1. *The General CODE-WA Approach*

As a general approach, the CODE-WA project worked via National Agricultural Research Systems (NARS) with local to regional farmers' organisations (FOs). While the NARS assured the scientific data collection, FOs facilitated the on-farm testing. The testing was executed at four sites along a zonal gradient involving sites in Niger (N-Sahel), Mali (S-Sahel), Burkina Faso (S-Sudan), and Ghana (N-Guinea). Table 1 has the full details of the zonal grouping. Major reasons for this choice were a distinct different natural and socio-economic environment i.e., subsistence-oriented in Niger and Mali vs. partly market-oriented in Burkina and Ghana, a minimum set of similar crops cultivated in these agro-ecological zones, accessibility in all seasons, and existence of a co-operating farmer organisation.

Table 1. Characteristics of CODE-WA Research Sites on a Zonal Climatic Gradient in Some Sahelian Countries.

Attributes	**Niger**	**Mali**	**Burkina Faso**	**Ghana**
Village	Serkin Haoussa	Tominian	Nobere	Wa
Geographic location	N 13.54' E 7.36'	N 13.12' W 4.26'	N 11.32' E 1.12'	N 9.96' W 2.45'
Bioclimatic Zone	Northern Sahel	Southern Sahel	Southern Soudan	Northern Guinea
Average (1951-2009) rainfall (mm)	510	680	980	1150
Rainfall range 2008-2010 (mm)	200-700	620-670	1040-1390	1030-1270
Vulnerability to climate change	Very high	High	Moderate	Low
Major crops	Pearl millet, cowpea	Pearl millet, sorghum, groundnut, cowpea, fonio	Maize, sorghum, cowpea	Maize, sorghum, millet, groundnut, cowpea
Dominant soils (WRB 2006)	Arenosols	Plinthosols, Acrisols	Luvisols Plinthosols	Ferric Luvisols, Lixisols Plinthosols, Cambisols

1.2. *The Opposite Pyramid Approach*

Due to the short duration of the project, the opposite pyramid approach (OPA) (See Fig. 1) was followed to allow for faster adoption of new agricultural options in a participatory manner. Since this approach is central to the project as well as for the data collection with respect to this paper, it is presented here in more detail.

Intervention areas. These were chosen by researchers based on expert knowledge and depending on availability of seed and scientific expertise of the project members i.e., no livestock interventions. Within the

CODE-WA project the approach was applied at the crop species as well as the varietal level, and will be explained here using pearl millet, which is WASAT's main staple cereal as an example.

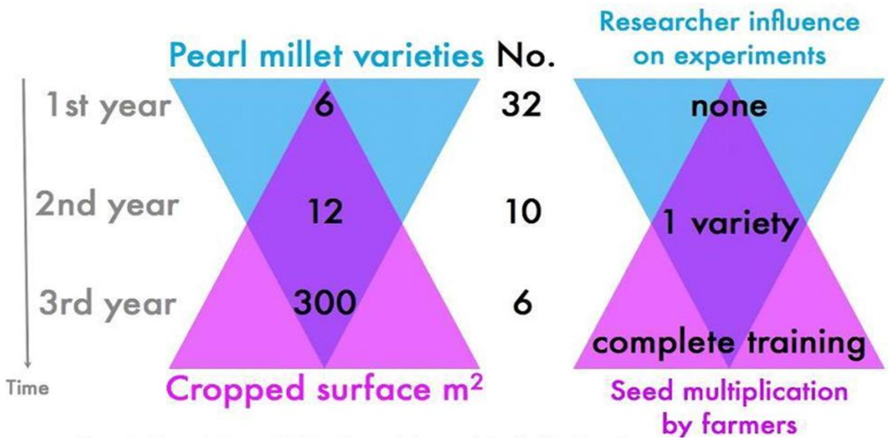


Fig. 1. Opposite Pyramid Action (OPA) Research Approach for Identification of Farmer Preference.

In the first year (2008), the same 32 pearl millet varieties differing for cycle length and other agro-morphological characters were introduced at each site of the project. Based on participatory evaluation during the season and grain yield data at final harvest, the number of varieties was reduced in subsequent years at each site. Since the decision on which cultivars to retain was done by the farmers, the number and kind of varieties tested in the following years varied among the sites. Within the tested set always 1-2 local varieties served as control. While in the first year (2008) the crop management was decided by researchers, the researchers' influence was consecutively reduced until the third year (2010) farmers had complete freedom in making management decisions including the use of intercropping. This procedure increases the potential adoption rate. Also, while the number of varieties was decreasing, the cropped surface per variety was increasing. This is considering the frequently observed soil micro-variability, including farmers' reality and increases the chances of adoption.

After identification of adapted farmer-preferred diversification options using the OPA, training of farmers on varietal conservation and appropriate methods of seed production is crucial, especially for open-pollinating crops, to assure durability of the diversification effort.

1.3. *Pearl Millet Trials Overview 2008-10*

Two different types of experiment were conducted with pearl millet: researcher-managed multi-location trials and farmer-participatory trials. The researcher managed multi-location experiments (G*E trials) were conducted over three years from 2008-2010 at different project sites in Niger, Mali, Burkina Faso, and Ghana. The number of tested pearl millet varieties was 32 in 2008 but was reduced to 20 in 2009 and 2010. The reduction was based on varietal performance and farmers' preference. To allow for comparison with introduced varieties, one or two local checks were always included. The latter differed from site to site. For all trials, a randomised complete block design (RCBD) was used. Please see Table 2 for more details.

Table 2. Pearl Millet Trials at the four CODE-WA sites during the 2008-2010 seasons in the Sahel.

	Niger	Mali	Burkina Faso	Ghana
G*E trials				

International Journal of Agriculture Innovations and Research
Volume 12, Issue 4, ISSN (Online) 2319-1473

YY	N of Rep/site	Management	N of Rep/site	Management	N of Rep/site	Management	N of Rep/site	Management
08	1/2	Fertilizer	3/1	Fertilizer	1/3	Fertilizer	3/1	Fertilizer
09	3/1	Fertilizer	3/1	Fertilizer	2/2	Fertilizer	3/1	Fertilizer
10	3/2	One with One without	3/1	Fertilizer	2/2	Fertilizer	3/1	Fertilizer
Pearl millet farmers participatory trials								
09	2/3	Farmers' management	6 (1R/tester)	Farmers' management	4 (1R/tester)	Farmers' management	1 rep	Farmers' management
10	2:3:3/3	Farmers' management	5/3	Farmers' management	1/3	Farmers' management	1/6	Farmers' management

N: number, R: repetition, YY: year.

In 2009 and 2010, farmer participatory trials were conducted. Based on the multi-location trial from 2008, farmers could choose the varieties they considered the most promising for their own site for further on-farm testing. In 2009, 10 varieties were tested at all sites, 8 introduced and 2 local check varieties. Due to the local decision making, the varieties in the farmer-participatory trials differed from site to site. In 2010, farmer organisations were completely free in deciding on the number of varieties to test and the crop management. Important to note is that the participation of women in conducting the trials increased continuously, especially in Serkin Haoussa, Niger.

1.4. *Description of Participatory Evaluation*

One of the central paradigms of the project was participation of farmers, both men and women, in order to guarantee relevance and sustainability of the intervention. Therefore, farmers were invited to evaluate crop varieties that had been grown near their villages. The crops were evaluated during the growing period and after harvest and additionally culinary tests were conducted.

The procedure of participatory evaluation was as follows: a reasonably uniform field repetition was chosen, non-transparent envelopes attached to each plot, and the same numbers of red, yellow, and green cards were distributed to farmers, with the numbers of cards per colour corresponding to the total number of plots to be evaluated. The meaning of the card colours was thoroughly explained to farmers. Then the farmers had to repeat the meaning in their own words. The red colour meant a total rejection of the variety; the yellow colour indicated ambivalence and need for potential further testing. Green stood for total acceptance without need for retesting. Farmers went around the plots without any comment to observe the trial before starting the vote. Voting took place separately and independently by gender. Each participant put one card (colour corresponding to the participant's perspective of the plot) into the non-transparent envelope attached to each plot. Participants were voting one by one to avoid the possibility of exchange with or influence of another person.

After counting the cards separately for each gender group, a so-called preference index [8] was calculated using the following formula: 100 x (number of green cards + 0.5 x number of yellow cards) / total number of participating farmers. The index ranges from 0-100 %, with 0 indicating complete rejection and 100 % high preference by all participants.

Furthermore, farmer interviews were conducted either individually or in groups in order to examine the reasons for their choice, as well as the advantages and disadvantages of the tested varietal options. Together with the quantified varietal performance, the gender-specific preference index laid the basis for next season planning.

Not only the varietal performance with regard to earliness and yield, but other agro-morphological characters are important to farmers i.e., processing characteristics such as ease of threshing, decortication, and grinding. For cash crops, uniformity as well as colour can also play a role. Finally taste and appearance of the final food product need to correspond to local habits. After harvest, the best performing preferred varieties were chosen for organoleptic testing. Two local dishes were usually determined by the participants and prepared under the supervision of experienced women. Processing behaviour, appearance, taste, and storage behaviour were evaluated, and the preference indices were determined using the same procedure as in the on-farm evaluation.

1.5. *Statistical Analysis*

GenStat software, specifically the 12th version, was used for conducting both descriptive statistical analysis and analysis of variance, commonly referred to as ANOVA. The results derived from these analyses are thoroughly presented in a series of tables, allowing for easy interpretation and comparison of the project data.

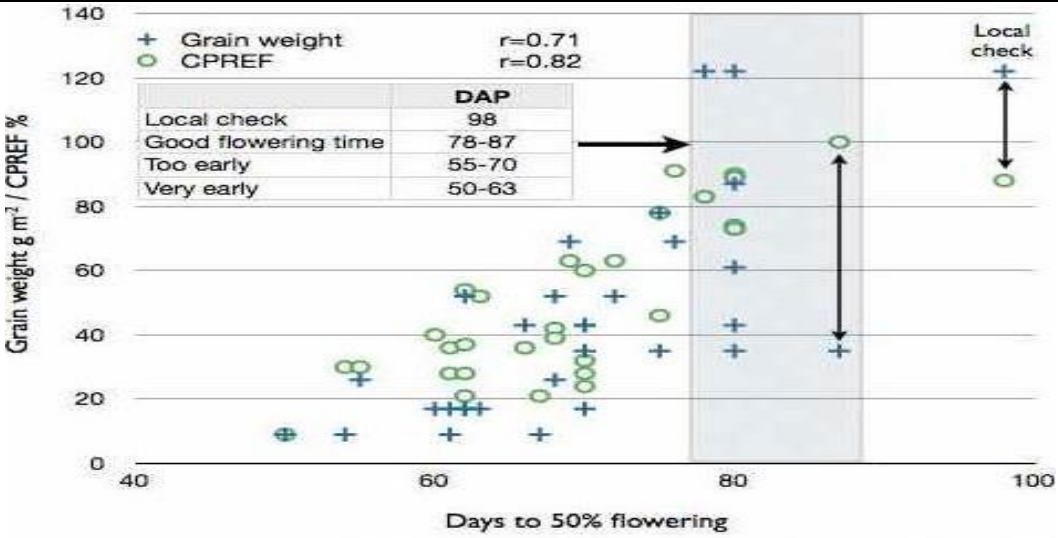
III. Results and Discussion

2.1. *Participatory Trials at Nobere, Burkina Faso*

The example of Nobore village in Burkina Faso (see Table 1) used to illustrate the decision pathway from the researcher-managed 32 pearl millet variety trial tested in the first year (2008) to finally 6 varieties tested on-farm in 2010. Factors and variables that influence farmers' choice during the participatory evaluation as well as gender aspects and culinary testing are considered.

Figure 2 shows the relationships among farmer preference index (18 men, 10 women), days to 50 % flowering and grain yield for the researcher-managed 32 pearl millet variety trial in Nobere, Burkina Faso for the 2008 season. A general positive linear correlation exists between date of flowering and grain yield with a correlation coefficient of r = 0.71. This means that under the given environmental conditions, flowering is an important trait and determines a great part of the yield potential. This is probably the major reason why the cumulative preference index (CPREF, averaged across women and men) is linearly correlated with grain yield in the same magnitude (r = 0.71). Only, the correlation with flowering date is higher (r = 0.82), which is underlined by the fact that maturity-related traits were mentioned 23 times when asked for reasons with respect to preference or rejection of varieties, while yield-related and other traits were only mentioned 14 times. Flowering date and grain yield explain together 92 % of the variance with respect to the CPREF while the gender-specific preferences were only explained to about 80 %. This is an indication of gender-specific preference, although the correlation coefficient between male and female PREF was r = 0.77. In fact, great differences of up to 70 % occurred among women's and men's preference index with respect to three varieties. In general, and this is also true for other sites, women tend to higher preference indices than men. In the case of Nobere, the average preference index over all varieties for women was 56 % and 48 % for men, though in 9 cases men had higher rating for specific varieties.

International Journal of Agriculture Innovations and Research
Volume 12, Issue 4, ISSN (Online) 2319-1473



	Grain weight g/m2	PREF Men	PREF Women	CPREF (%)
r flowering	0,71	0,79	0,75	0,82
r yield		0,64	0,69	0,71
additive r2		0,82	0,80	**0,92**

Fig. 2. The relationships among Farmer Preference Index (18 Men, 10 Women), Days to 50 % Flowering and Grain yield for the researcher-managed 32 pearl millet variety trial in Nobere, Burkina Faso for the 2008 Season.

The high additive r² with respect to CPREF is also an argument to rely on both genders for crop evaluation. The overall participatory rating also indicates a general problem of the varietal choice made by the researchers in the first year. Because in the activity planning meetings early maturity was indicated as most requested trait at all sites, absolute early varieties were included in the multi-location trial in 2008. But absolute early varieties showed a low yield performance, since they flowered at Nobere at the peak of the rainy season, which is risky for an open-pollinating crop due to pollen downwash and grain ripening under the rains. With respect to an optimal flowering date, farmers seem to be excellent observers. During the participatory evaluation, they characterised the range between 78 and 87 days after planting as best flowering date. And when one takes a look on the yield data, it becomes obvious that two introduced varieties reached the same grain yield as the late flowering local variety in approximately 20 days less time. Together with a third variety, which reached the optimum preference index of 100 % from women and men, they mark the boundaries of the best flowering period. It is interesting to note that this third variety was given optimal rating though grain yield was only about one third of the local check, and the latter achieved only 85 % with respect to the CPREF. This shows that the farmers took also yield potential and not only effective yield into account, since evaluation took place shortly before harvest in October.

2.2. *The Most Important Variables Mentioned by Farmers during the Evaluation*

Table 3. Selected agronomic traits and farmer preferences for pearl millet varieties in different seasons at Nobere, Burkina Faso (Data Only for the Repetition Evaluated).

Name	Country of Origin	50% FLO DAP 2009/08	Grain Weight g/m2 2010	Grain Weight g/m2 2009/08	CPREF % 2009/08	Positive/Negative Aspect	Aspect to Change
PE05572	Mali	70/69	-	11/69	64/63	Very early	Sowing date
PE05539	Mali	70/72	28	65/52	84/63	Early	Sowing date

Name	Country of Origin	50% FLO DAP 2009/08	Grain Weight g/m2 2010	Grain Weight g/m2 2009/08	CPREF % 2009/08	Positive/Negative Aspect	Aspect to Change
Guifou16	Mali	74/80	-	10/61	63/73	Very early	Sowing date
PE05980	BF	74/76	17	19/69	94/91	Big panicle, a bit early	_
PE00967	BF	74/80	-	39/35	100/73	Adapted cycle, long panicle	_
PE00456	Mali	75/78	-	41/122	94/83	Adapted cycle, big panicle	_
PE06001	BF	78/80	31	39/43	100/90	Adapted cycle, good production	_
PE00576	Mali	78/80	37	127/122	100/89	Adapted cycle	_
Early-Local		82/-	39	75/-	100/-	Adapted cycle	_
Late-Local		88/97	47	56/122	100/88	Adapted cycle	_
Average		76/79	33	48/77	90/79		

FLO: flowering, DAP: days after planting, CPREF: cumulative preference index (across men and women), BF: Burkina Faso.

During ono-on-one interviews, farmers mentioned two reasons for preference or rejection of varieties. These were the timing of flowering as an indicator of growing cycle length and the size of panicles as an indicator of potential yield. Therefore, these two variables are discussed in the following in more detail. Varieties which farmers considered as having appropriate flowering had a CPREF of 73 to 100 %. 100 % was reached only once for an unreleased variety with the acronym PE05432. In comparison to the local check which achieved 50 % flowering in 98 days after planting (DAP), preferred introduced varieties were in the range of 78-87 DAP. Varieties classified by farmers as too early or very early flowered within 50 to 75 DAP and were less preferred. Varieties having a CPREF of more than 60 % were characterised as flowering later 70 DAP meaning they do not belong to the group judged to be very early. This suggests that farmers want to have earlier varieties, but only in relative terms to their local cultivar, and the introduced variety should have the same yield potential as the local one.

The second most important criterion that farmers applied for their choice is linked to the size of the panicle, its length and compactness. The CPREF of varieties mentioned to have long or big panicles varies between 60 % and 89 %. Eleven varieties reached a yield higher than the arithmetic mean of 44 g m-2. All mentioned big panicles per say did not have a yield above average but 5 g m-2. Three varieties rated to be too early surpassed this threshold. CPREF for the varieties with above average yield ranged between 37-91 %.

Based on the results of all four CODE-WA sites in 2008 and applying CPREF and yield performance data 18 varieties were tested again in 2009 and 2010 in multi-location trials at all sites together with two 2 local varieties: one early and one late if available. At the Nobere site famers opted to continue in parallel participatory testing of 8 introduced and 2 local varieties.

Table 3 shows the selected agronomic traits and farmers' preferences for pearl millet varieties in different seasons at Nobere, Burkina Faso. The quantitative traits and the cumulative preference index for the 10 varieties tested in 2009 in Nobere in the participatory trials are compared for the different cropping seasons. Due to the restriction to later flowering varieties the average flowering date increased from 76 DAP in 2008 to 79 DAP in

2009 though the date to 50 % flowering decreased in general if compared on a single variety basis. The local varieties showed the longest cycles.

Although through the selection process preferentially higher yielding varieties were sown, the average yield decreased from 77 to 48 g m-2. A major reason was lack of yield stability of a number of varieties decided as being early or very early by local farmers i.e., PE05572, Guifoue 16, and PE05980. In 2008 these varieties showed above-average yield but had less than 20 g m-2 in 2009. This is mainly because of high susceptibility to downy mildew due to their origin from more arid areas, which frequently occurred under 2009 meteorological conditions in Nobere. This problem in millet production was observed by De Rouw [9], who reported that grain yields are usually below 500 kg ha-1 because of the low soil chemical fertility, drought, and poor or inadequate management systems. Also, two of the three highest yielding varieties in 2008, including the local late one, dropped sharply. The higher yield of the earlier local variety underlines the meaningful request of local farmers towards relative earlier but not absolute early varieties. In all maturity groups varieties with stable yield occur. This offers a good option for adaptation to variable climate conditions. PE05539 in particular was convincing for early maturity, and PE 00576 with a flowering date around 80 DAP is outperforming all the other tested varieties with respect to absolute yield and yield stability. CPREF results confirm the ones from 2009 and have the same range 63-100 % for the ten tested varieties. Due to the participatory choice the average CPREF increased to 90 %. The average rating increased again towards longer cycles (r = 0.59) and reached the optimum around 80 DAP to 50 % flowering. This time the cycle considered to be adapted started with 74 DAP, a little bit earlier than in 2008, but this fact must be seen in relation to the seasonal setting, when all varieties except one flowered earlier. As in 2008, adapted cycle length and appropriate panicle size were determining farmers' varietal choice in 2009. For the earlier varieties farmers proposed later sowing as adaptation strategy.

In 2010 farmers opted to test only 4 introduced varieties with preference indices higher than 84 % and including one early cultivar. These varieties were evaluated together with two local checks. In general, 2010 yield of pearl millet dropped again due to above average (too high) rainfall. Under this condition, together with soils which tend to water stagnation due to dense subsoil, the introduced varieties could not outperform the local ones, with the local late varieties showing the highest yield with only 47 g m-2. The best yielding introduced variety PE 00576 dropped to only 37 g m-2. Nevertheless, farmers preferentially and at will be decided on the basis of varietal potential and the best average yield over the three seasons to invest in seed production of this variety in 2011 on 0.75 hectare of land.

2.3. *Organoleptic Testing*

Earliness and yield are important traits for farmers as well as agronomists. However, since pearl millet is a staple crop finally also taste is important for the consumers, who are often the farmers themselves. Therefore, before investing in seed multiplication of agronomically preferred varieties, culinary testing is a precondition. Averages over two types of preparation (To, Zoom-yanse) and two consumption times reported in Table 4.

Table 4. Results for participatory organoleptic testing of four pearl millet varieties at Nobere, Burkina Faso in 2009.

Variety	PREF % Men	PREF % Women	CPREF %
Early local	90	97	94
PE06001	86	100	93

Variety	PREF % Men	PREF % Women	CPREF %
PE05980	85	99	92
PE00576	70	100	85

CPREF = Cumulative Preference index (across women and men).

Therefore, three highly preferred introduced varieties (CPREF >90%) were used to prepare local dishes for organoleptic tests in comparison to the early local. From all varieties 'To', (a kind of porridge) and 'Zoom-yanze', a drink-like preparation, were tested as local dishes. The 'To', as is traditionally practiced, was even left over night, and evaluated again in the morning.

In general, all ratings were high (> 70 % PREF) with men seemingly being more critical especially with respect to the highest yielding variety PE00576. Interestingly with this variety also the highest gap between men and women occurred, with women giving the highest possible rating. Since men are generally more interested in the agronomic traits and women responsible for preparation, the ratings are by no means critical for the adoption of the tested varieties.

2.4. *G*E Trial Trends Across Sites and Seasons*

Table 5 summarises grain yield data for pearl millet across sites and seasons in order to compare it with the farmer decisions. The first observation is that the coefficient of variation (CV) for in-site comparison is highest with lowest rainfall. Only exception is Mali where rainfall did only vary within narrow limits (600-700 mm). In fact, clear seasonal effects on yield patterns are detectable. For example, the Niger site experienced insufficient rainfall of only about 200 mm in 2009, which led to famine caused by very low to nil yields in the region. In contrast at the southernmost site in Ghana, rainfall amount was sufficient with more than 1000 mm in 2010 but a very uneven distribution, leading to late resowing in late July or even August and also a very late end of the season. Both described events explain the absolute yield minimal in comparison of environments. The maximal yields per year were always measured at Sahelian sites (2008 and 10 in Niger, 2009 in Mali). This is explained by the better adaptation of the pearl millet crop to more arid climatic and sandy soil conditions.

Table 5. Mean pearl millet grain yield data (g m^{-2}) across CODE-WA sites and seasons (2008 – 2010) for 20 varieties tested in multi-location Trials, b. Introduced Pearl Millet Varieties Chosen by Farmers for on-farm testing in the 2010 season.

	Niger			Mali			Burkina Faso			Ghana			Grand Mean
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	
ICMV-IS8930	150	2	140	32	56	15	14	10	43	103	27	24	51
B9_Tabi	188	20	122	12	43	11	14	8	47	104	20	20	51
PE03118	125	10	152	30	53	17	26	9	39	103	47	45	55
PE05571	125	6	122	54	53	19	32	11	43	87	70	47	56
PE05572	133	9	130	48	55	12	46	13	39	100	68	40	58
PE05908	129	8	170	41	59	20	35	7	59	88	45	50	59
Guifoue16	113	7	157	48	70	21	38	8	36	111	59	15	57
PE05645	104	19	178	48	79	13	29	7	35	115	44	30	58

International Journal of Agriculture Innovations and Research
Volume 12, Issue 4, ISSN (Online) 2319-1473

	Niger			Mali			Burkina Faso			Ghana			Grand Mean
	2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010	
PE05980	63	7	150	78	70	26	43	18	51	96	95	21	60
PE00253	125	21	205	41	62	15	46	10	51	92	58	55	65
Indiana05	104	5	181	78	66	19	52	28	59	95	65	21	64
PE05887	121	10	246	63	86	19	38	5	35	83	44	22	64
PE00456	96	6	194	60	72	11	78	30	39	107	76	31	67
Late_Local	104	2	197	63	54	25	87	39	43	97	25	60	66
PE06001	146	2	127	81	65	38	49	34	38	98	86	8	64
PE00576	25	1	224	88	78	14	81	41	43	98	82	14	66
PE02983	113	2	247	60	71	15	52	39	42	100	60	31	69
Early_Local	n.t.	2	292	n.t.	78	16	n.t.	37	41	n.t.	59	29	69
PE00967	83	3	216	72	89	20	58	40	39	136	69	15	70
PE05539	200	6	256	72	98	8	49	37	46	105	66	28	81
Min	25	1	122	12	43	8	14	5	35	83	20	8	NA
Max	200	21	292	88	98	38	87	41	59	136	95	60	NA
Average	118	7	185	56	68	18	46	22	43	101	58	30	NA
SD	39	6	50	20	14	7	20	14	7	12	20	15	NA
CV	33	83	27	35	21	38	44	65	16	12	35	49	NA
Rainfall	450	198	507	664	626	661	1124	1037	1387	1266	1160	1034	NA

NA: Not applicable.

Maximum yields reached or surpassed 2 tons per hectare in 2008 and 2010. Also, the highest average yields per year were reached under Sahelian conditions. Grand means per site over the three seasons show a decreasing trend towards the wetter south. The higher grand mean for Ghana can be explained by the fact that these trials were executed under on-station conditions, since the co-operating farmer organisation did not have the capacity to execute such rather sophisticated trials. In addition, the Burkina site suffers partly from soils with tendency to water stagnation, for which pearl millet is not tolerant.

With respect to varietal trends, the local varieties which differed from site to site occur in the upper third with respect to mean performance over sites and seasons, with the local early usually performing better than the late local check. Nevertheless, five varieties could outperform the late local and two the early local check. These results justify the request of farmers for earlier varieties. From site to site the order differs and will not be detailed here, apart from two aspects. Taking the example from Ghana shows that introduced varieties can outperform the local varieties in normal and good years, but it is the late local one which yielded highest in the bad year 2010. Consequently, taking risk aversion and resilience into account, it is difficult to outperform the local varieties. Therefore, varieties which have a potential for adoption should have a better yield potential than the local variety in good years and at least a similar minimum yield in bad years.

The second aspect concerns the participatory variety choice of farmers for on-farm testing in 2010. According to the OPA applied, farmers were free to choose varieties and management in the third cropping season. It was observed the number and type of varieties changed from site to site. Nevertheless, some varieties seem to perform well across sites, which are PE 05339 for the three northernmost sites and PE 6001 for the three southernmost sites. It should be investigated in detail, which traits lead to such a high plasticity with respect to highly diverse environmental conditions.

Table 6. Farmer requested traits for pearl millet at the four CODE-WA sites, from left to right with increasing rainfall, ranked according to importance-number and order of mentions.

Niger (Northern Sahel)	Mali (Southern Sahel)	Burkina Faso (Southern Soudan)	Ghana (Northern Guinea)
Early maturing, high yielding, drought resistant, long and big panicles, large grains, long stalks (for women). Resistant to pest and diseases, resistant to striga, easy to process	Early maturing, high yielding, drought resistant, well-filled panicles	Early maturity, adapted reproductive cycle, high yielding, long panicles/well filled, resistant to pest and diseases	Early maturing, big panicle with big grains, good grain quality, grain color, resistance to diseases

Table 6 summarises farmer-requested traits for pearl millet at the four CODE-WA project sites mentioned in order of importance. Earliness is the first on the top of the list at all four sites. However, as shown for the example of Burkina Faso, this does not necessarily mean absolute earliness in terms of the specific crop but may differ from site to site depending on the specific climatic conditions. There is rather an optimum flowering period at each site outside which a cultivar won't be performing well. Further discussions with farmers on this specific topic during a farmer exchange visit with participants from all four countries revealed that the Sahelian and driest Niger and Mali sites share a common definition. At these sites an early maturing variety is one that when planted at the beginning of the rains should reach maturity with the end of the rainy season. Since these sites are in the Sahel at the northern climate boundary of annual cropping this statement means more or less absolute early varieties. However, synchronisation with the other locally used varieties is mandatory in order to minimise losses by bird attack.

For the southern sub-humid Burkina Faso and Ghana sites an early variety is one which can be planted about two weeks after the local late variety, flowers after the peak rains and matures soon after the end of the rainy season and earlier than the late local variety, which is usually harvested in December or even later.

With respect to the observed climate variability both definitions may cause certain problems for breeding. The "Sahelian definition" is based on an adaptation to the effective length of the growing period, which is facing a lot of irregularity, i.e., with drought spells at any time during the rainy season. Taking Serkin Haoussa in Niger as northernmost site as example, the vegetation period can begin on Julian (JD) 90 and end at JD 300 with the average start at JD170 and the average end at JD265. The "subhumid definition" is relative to the planting date and allows for maturation after the rains. But also, at the Ghana site we experienced in 2010 a shift of the vegetation period with late beginning, resowing in July and finally a late end in November. This poses a problem for varieties which are in these southern environments more photoperiod sensitive.

Table 7. Farmer requested traits for other common crops at CODE-WA Sites.

Cowpea	Groundnut	Sesame	Hibiscus
Early maturing, resistant to insects and diseases, high yielding, long and good pod filling, grain color (white), high market value	Early maturing, drought resistant, resistant to rosette virus disease, high yielding varieties, vigorous and good pod filling, easy to shell, high oil content and very good quality paste	Early maturing, drought resistant, Resistant to pests and diseases, high yielding, uniformity of seed color, high market value	Early maturing, drought resistant, more resistant to insect attack, easy to harvest, many leaves

Early maturing in the farmers' terminology means relative shorter growing cycle (approx. 7-20 days) in comparison to the local variety. Since often also several local varieties with different growth cycles exist, caution is necessary to evaluate what early maturing in the local context really means.

The second most important farmer requested trait at all sites is high yield. This refers to the final quantity of the grain after processing (threshing, dehulling or decortication). However, in the field farmers relate yield performance to other visible traits such as big or long panicles, large grains, and good grain filling. Varieties having these visible traits are preferred due to the expected yield per unit area. Coupled with earliness it can help to overcome the hunger period before traditional harvesting time of local staple crops.

Another important trait for the Sahelian sites is drought resistance. Since under Sahelian conditions early sowing is connected with high yield potential but early rains are unreliable, adapted varieties should resist especially early droughts since consequences of these are multiple sowing dates thus seed shortage, and shortening of the growing period and consequently low yield.

Another trait mentioned at all sites is resistance to pests and diseases including the parasitic weed striga (Striga hermonthica (Del.) Benth.). Though not directly related to climate variability these factors cause high yield losses. Adapted breeding strategies could help to reduce yield losses i.e., by escape strategies, and thereby contribute to resilience of farmers facing indirect climate impacts.

Other common crops like groundnut, cowpea, sesame, hibiscus etc. have also been evaluated (see Table 7). Apart from early maturation, which is also here the dominantly requested trait for these cash crops, drought and pest resistance are more important than high yielding. And quality aspects like uniformity of grain or specific colour come into the play because they have influence on the market value.

What do all farmers want? An early maturing, disease- and drought-resistant variety that adapts to the local environmental conditions. Consequently, more site-specific breeding strategies need to be developed apart from concentrating on high yields.

A last word with respect to early maturing varieties. In order to better understand the reasons behind this dominantly preferred trait across different crops, group discussions were executed at the different CODE-WA sites. As expected, climate-related concerns were dominantly stated, especially in the Sahelian region. This is underlined by the frequency of varieties changed in the recent past on the climatic gradient as exemplified by the northern- and southernmost sites of the CODE-WA project (Table 8). Climate induced variety changes are much faster at the northernmost site, while with respect to varieties nearly nothing has changed at the southernmost site. Farmers in Niger are continuously losing varieties and replacing them by other varieties from other parts of the country or neighbouring countries, from research stations or projects. Highest turnover concerns the staple crops millet, sorghum, and cowpea. With respect to diversity these figures do not indicate a-

-ny negative trend.

Table 8. Comparison of Lost/Introduced varieties of main crops in Serkin Haoussa, Niger and Piisi, Ghana.

	Serkin Houssa (Niger) Northern Sahel	Piisi (Ghana) Northern Guinea
Pearl millet	1/7	0/0
Sorghum	3/7	0/0
Cowpea	4/7	0/1
Peanut	0/4	-
Maize	-	0/1

Apart from climate concerns, the second most important reason asking for early maturing varieties is the market price. Earliness for cash crops like groundnut and okra means a several-fold higher market price. Depending on their geographical origin, early varieties can be more drought resistant. In addition, early maturing crops/ varieties are considered as hunger crops, as it is true for i.e., fonio in Mali. They help avoiding famine by bridging the time to the "normal" harvest of major staple crops.

Another reason is pest attack. Earliness can allow escaping or avoiding the susceptible stage of certain pest attacks. Also escaping yield loss due to transhumant herds was mentioned. Especially northern sites suffer from transhumant herds travelling southwards towards the end of the rainy season. Earliness allows farmers to harvest their crops before the arrival of the herds and thus avoiding violent conflicts with the transhumant herders. An additional argument is the better workload distribution. Using different sowing and harvesting dates reduces demand for external labourers. For the southerly sites long duration varieties which are sown earlier are more prone to early-season droughts, and multiple sowing might be required. Additionally, more weeding and other control measures need to be executed. Early varieties also allow finalising agricultural activities earlier in time in order to invest in off-farm activities. All these reasons play a role for farmers to request early varieties.

2.5. *What Strategy for Breeding Programs in West Africa*

Defining an appropriate range of flowering date in a target region is critical for the development of adapted and high-yielding cultivars. Due to variable planting dates, photoperiod-sensitive flowering is an important adaptation trait which can be mainly found in longer-cycle sorghums and pearl millets grown in the Sudanean zone of West Africa. Photoperiod-sensitive cultivars flower at a certain date determined by day-length changes, independent of their date of planting. Their vegetative cycle is extended in case of early planting but shortened in case of late planting. This trait needs to be maintained in improved cultivars as it assures adaptation to the highly variable beginning of the rainy season. However, the threshold day length for flowering may need to be adapted in future if seasons become shorter during the course of climate change.

Because of the diverse and changing environmental conditions and the diverse, partially gender-specific, farmer preferences even within one site, participatory breeding strategies that aim to “offer a wide diversity of material to the wide diversity of farmers” [7] are particularly promising. The CODE-WA project has confirmed that farmers are very keen to test new crop and cultivar options in a participatory manner. Taking this approach further, participatory breeding programs where breeders and farmers work together to adapt a diversified population to local needs are of high interest. Participatory approach allows obtaining the potential benefits of breeding which aim the specific adaptation. Opposed to the large concept of adaptation, specific adaptation is the resultant of a better valorization of the concept of GXE (Genotype X Environment). Recent research has shown that pearl millet populations selected by farmers in a participatory breeding program in Niger were able to adapt even outside their sites of selection while meeting local farmer needs, pointing to the potential impact of such participatory breeding programs beyond the intervention sites, and the benefits of farmer-researcher cooperation [10].

Once new cultivars are developed or identified in a participatory manner, the opposite pyramid approach that combines participatory variety evaluation trials with training in seed production is especially suitable for achieving sustainable systems diversification. Such a systems diversification-cultivating a set of complementary and diverse crops and cultivars reduces the vulnerability and enhances production stability of the system. Therefore, breeders should not aim to completely replace local varieties or try to develop a “one-size-fits-all” cultivar, but rather encourage and empower farmers to cultivate a diverse set of crops and cultivars.

Cultivating diversity and tactical crop or variety choice may be optimised once seasonal climate predictions become more reliable at a farmer-relevant scale, and once seed systems in West Africa are better developed to be able to respond to dynamic and changing seed needs for diverse crops and cultivars.

IV. Conclusions and Further Direction of Investigation

Our study focused on identifying farmer-requested traits for major crops, particularly pearl millet, in West Africa's semi-arid climate, with most highlights on several critical findings. The participatory approach, incorporating the OPA, revealed that farmers prioritize traits such as early maturation, high yield, and drought resistance in pearl millet varieties. The study's multi-location trials across the West African climate gradient demonstrated significant varietal differences in terms of yield, flowering time, and farmer preference. The research underscores the importance of aligning breeding programs with farmer preferences and local climatic conditions. It is evident that earliness in pearl millet is a highly valued trait across diverse agro-ecological zones, as it helps in mitigating risks associated with climate variability and enhances food security; this is crucial to most local farmers.

Breeding programs should be developed and promoted for pearl millet varieties that align with the key traits identified by farmers, especially early maturation, while ensuring high yield and drought resilience. This approach will enhance the adoption of improved varieties and contribute to agricultural sustainability in the region. Also, participatory breeding should continue and expand the participatory breeding approach, involving farmers in the selection and evaluation process. This will ensure that the developed varieties are well-suited to local conditions and farmer needs in different contexts. Diversification and resilience should be encouraged in the cultivation of a diverse set of crops and varieties to reduce vulnerability and enhance system resilience. This strategy is particularly important in the context of increasing climate variability and uncertainty in order to reduce risks. Extension and training should be encouraged to strengthen extension services and farmer training programs to disseminate knowledge about the new varieties and their management practices. This will facilitate the effective adoption of improved varieties and also enhance crop productivity in general. Therefore, it recommended to conduct further research to understand the genetic basis of the traits preferred by farmers and explore the potential for developing varieties with broader adaptability across different environmental conditions.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge funding by the German Ministry for Economic Collaboration and Development in the frame of the ICRISAT-CODE-WA project as well as the contributions of the collaborating national research institutions and farmer organisations (INRAN / Fuma Gaskiya - Niger, IER / UACT - Mali, INERA / UDPN - Burkina Faso, SARI / MOFA / KWG - Ghana).

REFERENCES

[1] M.T. Daramola, E.O. Eresanya, and S.C. Erhabor, "How has aridity changed over West Africa in the past four decades?," Journal of African Earth Sciences, vol. 197, pp. 104745, 2023.
[2] J. Villamayor, M. Khodri, S.W. Fang, J.H. Jungclaus, C. Timmreck, and D. Zanchettin, "Sahel droughts induced by large volcanic eruptions over the last millennium in PMIP4/Past1000 simulations," Geophysical Research Letters, vol. 50, no. 5, pp. e2022GL1014 78, 2023.
[3] A.J. Dietz, R. Ruben, and A. Verhagen, The impact of climate change on drylands: with a focus on West Africa: Springer, 2004.
[4] A. Coudouel, S. Fuselli, and M. Saidi, "Stress Testing Adaptive Social Protection Systems in the Sahel," 2024.
[5] R. Thomas, "Opportunities to reduce the vulnerability of dryland farmers in Central and West Asia and North Africa to climate change," Agriculture, Ecosystems & Environment, vol. 126, no. 1-2, pp. 36-45, 2008.
[6] M. Brüntrup, "The level of risk aversion among African farmers–results of a gambling approach."
[7] K. Vom Brocke, G. Trouche, E. Weltzien, C. P. Barro-Kondombo, E. Gozé, and J. Chantereau, "Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria," Field Crops Research, vol. 119, no. 1, pp. 183-194, 2010.
[8] E. Weltzien, and A. Christinck, "Identifying farmers' preferences and needs for varieties and specific traits," Setting breeding objectives and developing seed systems with farmers. Handbook for practical use in participatory plant breeding projects, pp. 83-104, 2005.
[9] A. De Rouw, "Improving yields and reducing risks in pearl millet farming in the African Sahel," Agricultural Systems, vol. 81, no. 1, pp. 73-93, 2004.
[10] S. Haffke, "Assessment of different methods of farmer-participatory selection in diversified pearl millet [Pennisetum glaucum (L.) R. Br.] populations at three pilot sites in Niger," University of Hohenheim, Germany, 2010, 2010.

AUTHOR'S PROFILE

First Author

Dr. Hannatou Moussa Oumarou, is a researcher at the National Institute of Agronomic Research of Niger (INRAN). She has played a key role in the development and dissemination of seedball technology, particularly in the Sahel region of Niger, which is known for its challenging cropping environments. Dr. Oumarou's work focuses on enhancing agricultural practices to improve yields and support smallholder farmers, especially women, in these regions. Dr. Oumarou's contributions to the seedball technology project are significant. She has been actively involved in training local farmers, including women, on how to use seedballs effectively. This technology is advantageous as it helps in increasing the germination and growth of crops like pearl millet and sorghum, which are crucial for the livelihoods of farmers in these areas. Seedballs, which contain essential nutrients like nitrogen, phosphorus, potassium, and wood ash, create a favorable microenvironment for seeds, thereby enhancing their chances of survival and growth, especially in drought conditions. The success of the seedball technology under Dr. Oumarou's guidance is evident in the increased yields and improved farming practices reported by local farmers. The technology has been scaled to numerous villages, reaching thousands of farmers, and has demonstrated its effectiveness in increasing crop yields significantly. Dr. Oumarou's leadership and dedication to working with subsistence farmers, particularly women, have been instrumental in the widespread adoption and success of this innovative agricultural technique. Dr. Oumarou's enthusiasm for agricultural research and her efforts to improve the lives of smallholder farmers are reflected in her dedication to the seedball technology project. Her work, along with the collaborative efforts of other researchers and organizations, continues to make a positive impact on agriculture in the Sahel region, contributing to sustainable farming practices and enhancing food security in the Sahel and beyond.

Second Author

Dr. Charles Ikenna Nwankwo, is a Nigerian-born German Researcher associated with the University of Hohenheim in Germany, specifically the Institute of Soil Science and Land Evaluation. He holds a Ph.D., and his research interests are diverse, encompassing crop physiology, soil fertility, soil analysis, soil chemistry, biological nitrogen fixation, field experimentation, nutrient cycling, biostatistics, plant nutrition, sustainable agriculture, and dryland agriculture. His Ph.D. work focused on the development and implementation of seed ball technology into Sahelian pearl millet production systems. Dr. Nwankwo's current position is a postdoctoral role at the Soil Science and Pedology department of the University of Hohenheim, where he is involved in enhancing and disseminating seedball technology in the West African Sahel. This technology is particularly significant in regions like the Sahel, known for harsh cropping environments. The seedball technology has been successful in improving seedling establishment and yield, especially for crops like pearl millet and sorghum. It involves using locally available materials to create seed pellets that enhance crop establishment and early biomass production. The technology has been scaled to various villages and has shown great promise in increasing yields and supporting sustainable agricultural practices. It is especially beneficial for smallholder farmers, including women, who often cultivate less fertile lands. Seedballs help protect seeds underground, providing nutrients and moisture, and mitigating seed loss due to pests. The adaptability of the technology allows it to be customized to local conditions, addressing issues like low soil nutrients or pest challenges. Dr. Nwankwo's work on seedball technology is part of broader efforts to improve agriculture in challenging environments and contribute to sustainable farming practices.

Third Author

Mr. Ali Maman Aminou, is an Agronomist and the Director of FUMA Gaskiya, a federation of farmers' unions in the Maradi region of Niger. He is also the Principal Investigator (PI) of the McKnight Foundation's Collaborative Crop Research Program (CCRP)-sponsored Women's Fields project in Niger. This project focuses on various context-specific agricultural options, including low-cost fertilization methods using human urine. FUMA Gaskiya, under the leadership of Mr. Aminou, has been actively involved in agricultural research and the promotion of agroecological practices. The organization, which has over 20,000 farmer members, of whom 53 percent are women, is organized into district-level unions and village-level farmer groups.

Fourth Author
Prof. Dr. Ludger Herrmann, is a prominent figure at the University of Hohenheim in Germany. His academic focus and research contributions span a wide range of topics related to soil science, agricultural practices, and environmental sustainability. Prof. Dr. Herrmann's work includes extensive research on seedball technology, particularly its optimization for pearl millet production in challenging environments like the Sahel region in Africa. This research is critical for improving agricultural practices and crop yields in areas facing climatic and soil challenges. His contributions also extend to studying soil properties and management, with an emphasis on sustainable agriculture and environmental conservation. In addition to his research on seedballs and soil science, Prof. Dr. Herrmann has explored various topics such as the use of gamma spectrometry for soil mapping and the effects of soil-forming factors on different regions. His work has been published in numerous peer-reviewed journals, demonstrating his commitment to advancing knowledge in soil science and agricultural methods. Prof. Dr. Herrmann's role at the University of Hohenheim and his extensive research output highlight his significant contributions to the fields of soil science, agriculture, and environmental studies.