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Hydropriming of pearl millet (*Pennisetum glaucum* L.) in Northern and Central Burkina Faso applying six hours of soaking and overnight drying of seeds

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Hydropriming of pearl millet seeds was tested during two growing seasons in Burkina Faso. A total of 32 field experiments were distributed equally between two agro-ecological zones: The Northern zone receiving on average less than 600 mm annual precipitation and the Central zone receiving 600 to 900 mm. Hydropriming was performed by soaking of seeds in water for 6 h, followed by air-drying overnight. In the Northern zone, an increase of both emergence and yield was observed for hydroprimed seeds in both years of testing. This was reflected by a higher yield observed in 13 out of 16 field experiments, increased median yield (+159 kg/ha; *p*<0.0053) and an increase of the relative yield by +29% as a field average (*p*<0.000054). In contrast, in the Central zone a net negative effect on crop emergence was observed in both years, and only 5 out of 16 field experiments showed a yield increase for hydroprimed seeds. Meteorological data confirmed the difference in rainfall between the two zones. Hydropriming by 6 h of soaking and drying of seeds overnight appears as a simple method to increase yield of pearl millet significantly in the most arid out of two agro-ecological zones tested in Burkina Faso. Drying of seeds overnight is a novel agronomically feasible approach, allowing a full day for subsequent sowing.

Key words: Seed-priming, hydro-priming, Sahel, millets, location-dependent effect.

INTRODUCTION

Hydropriming has been proposed as a seed treatment to improve crop establishment and yield (Harris, 1996; Harris et al., 1999; 2001 a, b). In general, the method includes soaking of seeds in water for a number of hours followed by a short (<2 h) drying of the seeds before sowing. The method has been studied mostly in subtropical/tropical and semi-arid areas where the method has been shown to improve crop establishment particularly under constraints of water deficiency and high temperatures (Harris, 2006; Navaz et al., 2013).

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In both finger millet and pearl millet, grain yield increases of 13 to 30% have been obtained by soaking of seeds for 8 to 16 h in water (Kumar et al., 2002; Aune and Ousman, 2011; Aune et al., 2012; Jidda and Anaso, 2017). Despite the simplicity and inexpensive nature of the methodology and despite several demonstrations of yield increases in millets, the technology has only sporadically been taken up by farmers. Lack of knowledge is probably not the only reason for this. The method has some practical drawbacks in terms of organizing the field work of sowing: The drying of seeds for 2 h before sowing has the implication that the physical work of sowing (typically by hand) cannot start immediately in the morning, where working conditions in the tropics are most convenient. In order to circumvent this, we tested the possibility of drying seeds overnight (16 to 20 h). In order to further maximize the flexibility of the method we also reduced the generally recommended time for soaking (8 h) to only 6 h since laboratory studies have shown that soaking of pearl millet seeds for just 6 h is sufficient to cause a strong and positive response in seedlings (germination and seedling vigour) (Akbar et al., 2009).

Two agro-ecological zones in Burkina Faso were chosen for the testing: The Northern zone, situated North of 13°N latitude receiving less than 600 mm precipitation per year and the Central zone situated between 11 to 13°N latitude receiving 600 to 900 mm precipitation per year on average (De Longueville et al., 2016). The Northern zone (synonymous with *Sahelian* zone) is primarily characterized by dry-land agriculture including pearl millet as the main crop (INSD, 2016). The Central zone contains the capital, Ouagadougou. In the surrounding rural districts pearl millet is second to sorghum in terms of the area cultivated (INSD, 2016). It has previously been shown that the effect of hydropriming is dependent on humidity of the soil (Harris, 2006). Given the difference in annual precipitation, it appeared relevant to compare the effect of hydropriming in the two zones.

MATERIALS AND METHODS

Seed material

For each of the two years (2015 to 2016) a seed sample of cultivar, You Local, propagated during the previous year, was used for field experiments. You local is a landrace originated from the village, You (Figure 1), and is propagated by INERA (Burkina Faso).

Seed treatment

Hydropriming was conducted by soaking of seeds for 6 h in pure water at ambient temperature (around 25°C). Before sowing, seeds were subsequently air-dried over-night (16 to 20 h). Air-drying was conducted by spreading of seeds in a uniform layer of 0.2 to 0.5 cm on a piece of cloth or on a layer of blotter paper (a water absorbing material). Non-soaked seeds were used as the control.

Experimental fields

For two subsequent growing seasons, 2015 to 2016, a total of thirty two field tests were carried out comparing non-treated seeds of pearl millet to seeds hydroprimed and dried as described above (Figure 1). On each field, two plots (25 rows, 5 m long) were laid out side by side, and sown with the two types of seeds, respectively. For each of the two years, sixteen field tests were conducted – eight in Northern Zone and eight in Southern zone, respectively. In 2015, experimental fields were located near three different villages in each zone; in 2016, fields were located near 4 different villages in each zone as indicated in Figure 1. Before sowing, ploughing was done by tractor at Kamboinsé (Research station), whereas at the other locations (farmers' fields) ploughing was done by donkey or cow. Sowing of seeds was done by hand at 5 to 7 cm depth, using six to eight seeds per seed hole. Seeds were sown in rows with distances of 0.80 m between rows, and 0.60 m between holes in the same row. This corresponds to a seeding density of approximately 146.000 seeds ha^{-1} (estimated). For each village, a common time point for seed treatment and sowing was chosen within the normal sowing period (June to July) taking local weather conditions and forecasts into account.

Management and measurements

Fifteen days after sowing, the number of emerged seedlings was reduced to a maximum of 3 seedlings per seed hole. The first weeding was done 15 days after sowing, and subsequently when needed (optional). Mineral fertilizer consisting of Nitrogen-Phosphate-Potassium (NPK 14-23-14) was applied at 100 kg ha^{-1} 15 days after sowing. Urea (50 kg ha^{-1}) was applied 30 days post-emergence. Three to four weeks after sowing crop emergence was determined visually by counting the percentage of seed holes populated with emerging plants. At harvest (October-December), grain was collected from the whole plots, and sun-dried for 2 weeks before weighing to determine the yield. Data of monthly precipitation (2015 to 2016) in the Northern zone was obtained from Direction Provincial of Agriculture and Hydraulic Facilities of Loroum (DPAAH-L). Corresponding meteorological data from the Central zone was obtained from Kamboinse Environmental, Agricultural and Training Research Center (CREAF-K).

Statistics

Mean and median values were calculated for both emergence (%) and yield (kg/ha). In addition, the relative yield (%) compared to the field average (average of both treatments within each field) was also calculated. Medians were compared using Wilcoxon test for related samples ($p<0.05$). Means were compared using t-test ($p<0.05$). Statistical software PAST (version 2.17c) was applied for the analysis (Hammer et al., 2001).

RESULTS

Effect of hydropriming in Northern zone

A positive effect of hydropriming was observed in both growing seasons (Table 1, Northern zone). In total (both years), the median emergence increased from 68.1 to 75.2%, and the median yield increased from 859 to 1018 kg/ha (+ 159 kg/ha). The latter finding was statistically significant ($p<0.0053$), and reflected an increase of the

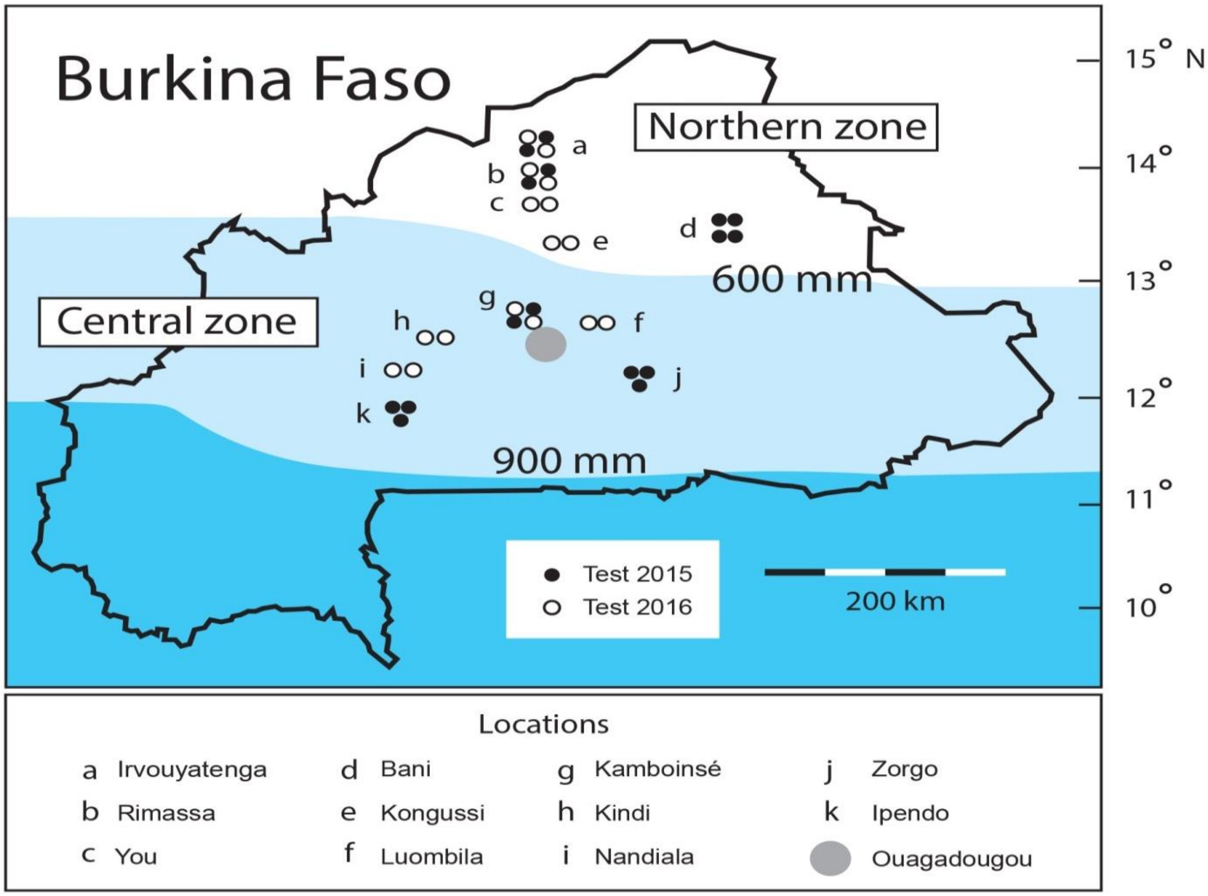

Figure 1. Field test locations 2015-2016.
Blue colors indicate average annual rainfall (De Longueville et al., 2016).

yield for hydroprimed seeds observed in 13 out of 16 fields. When yields were calculated relative to the field average, the overall effect of hydropriming was equivalent to a mean yield increase of 29% (Table 1; 112.6 relative to 87.4, $p<0.000054$).

Effect of hydropriming in Central zone

In the Central zone, only 4 out of 16 fields showed a positive effect of hydropriming on emergence and for the yield, an overall 7% decrease was observed (Table 1, 96.4 vs. 103.7, non-significant).

Effect of hydropriming in total (both zones) and meteorological data

By combining figures from both years and both zones (Table 1, Total), an overall yield increase of 9.4% (Table 1; 104.5 vs 95.5) was found as barely significant ($p<0.049$). No consistent change of emergence was observed (Mean emergence increased by approximately 1%, and median emergence decreased by approximately 2 %). Meteorological data obtained for 2015 and 2016 confirmed the expected difference between the two zones with regard to patterns of precipitation (Table 2). Both during crop establishment (June to July) and during the full growing season (June to October), the Northern zone received less rainfall than the Central zone in both years.

DISCUSSION

Comparison to other studies

In the present study, we found a reproducible and highly significant positive response of pearl millet to hydropriming in one of two agro-ecological zones tested: The Northern zone. In this zone, both emergence and yield were observed to increase in both years of testing (Table 1), and when data for the two years were combined, the effect on yield was very significant (Yield relative to field average was increased by 29% from 87.4 to 112.6, $p<0.000054$).

Table 1. Emergence and yield in field experiments (two zones, two years).

Variable	Northern zone		Central zone		Total	
	NoT	W-6	NoT	W-6	NoT	W-6
Emergence						
2015 (N=8 per zone) mean (%)	78.0	82.4	79.3	72.3	78.7	77.4
2016 (N=8 per zone) mean (%)	55.5	65.7	78.4	74.9	67.0	70.3
Total mean (%)	66.8	74.1	78.8	73.6	72.8	73.8
Total median (%)	68.1	75.2	77.6	72.4	75.1	73.4
Fields with higher emergence	ns	10 (16)	ns	4 (16)	ns	14 (32)
*p-value**	ns	ns	ns	ns	ns	ns
Yield						
Absolute (kg/ha)						
2015 (N=8 per zone) mean (kg/ha)	703	1019	1094	1213	899	1116
2016 (N=8 per zone) mean (kg/ha)	982	1247	973	841	978	1044
Total mean kg/ha	843	1133	1034	1027	938	1080
Total median (kg/ha)	859[a]	1018[b]	1064	1042	916.7	1031
Fields with higher yield	ns	13 (16)	ns	5 (16)	ns	18 (32)
*p-value**	ns	<0.0053	ns	ns	ns	ns
Relative (% of field average)						
2015 mean (%)	84.8	115.2	96.4	103.6	90.6	109.4
2016 mean (%)	90.1	109.9	110.9	89.1	100.5	99.5
Total mean (%)	87.4[a]	112.6[b]	103.7	96.4	95.5[a]	104.5[b]
*p-value***	ns	<0.000054	ns	ns	ns	<0.049

NoT = No treatment; W-6 = hydropriming (6 h).*Medians with same letters are not significantly different (Wilcoxon paired analysis, $p<0.05$). **Means with same letters are not significantly different (t-test, $p<0.05$).

Table 2. Precipitation in Northern and Central zone 2015-2016.

Variable	Precipitation (mm)			
	Early crop season (establishment) (June- July)		Whole growing season (June-October)	
	Northern zone*	Central zone**	Northern zone	Central zone
2015	211.0	346.4	629.0	837.0
2016	280.0	322.3	545.9	819.0
Average	245.5	334.4	588.0	828.0

*Climate station at Titao; ** Climate station at Kamboinsé.

In contrast, no consistent positive effect was observed in the Central zone, and the meteorological data confirmed a higher level of rainfall for this zone in the growing season (Table 2). The result of 29% yield increase obtained in the Northern zone (13 to 15°N latitude) is very similar to results obtained in two other countries in the Sahelian region with field experiments carried out at similar latitude. In neighbouring country Mali (13 to 14°N), a yield increase of 30% in pearl millet was found as a mean of 27 field experiments (Aune et al., 2012), and in Sudan (13.1 °N) a yield increase of 15% was found at a research station and 30% increase was found in farmers' fields as a mean of 25 repetitions (Aune and Ousman, 2011).

For the related cereal species, Sorghum, a recent study in Sudan (at 12°N) found a manifest effect on yield (27% to 76% increase) using hydropriming of seeds in areas having around 600 mm annual rainfall; the strongest effect was observed in plots also receiving a high dose of mineral fertilizer, and all seeds were treated with pesticide after drying (Abdalla et al., 2015). All the three aforementioned studies, have applied 8 h of soaking and

1 to 2 h for drying of seeds.

Thus, with respect to the Northern zone of Burkina Faso, the results presented here is in line with previous positive results for both millet and sorghum in the Sahelian region (receiving close to 600 mm rainfall or less per year). At the same time, this study provides a new, flexible protocol applying a shorter soaking time (6 h) and drying of seeds overnight, thereby allowing sowing to start early next day. However, the negative results obtained in the Central region clearly indicate that agro-ecological differences should be taken into account with regard to development and evaluation of seed treatment technology – including hydropriming. The reason for the negative results obtained in the Central zone is unknown at present, but the meteorological data confirmed the higher level of rainfall during the period studied in the Central zone.

Previously, it has been reported that higher soil humidity is associated with a lower effect of hydropriming in pearl millet (Harris, 2006), and in other cereal crops (wheat and sorghum) a weak response to hydropriming was reported for areas and for years with high precipitation (Harris et al., 2005; Ramamurthy et al., 2005).

Theoretical context of results

The general physiological effects of hydropriming have recently been reviewed (Lutts et al., 2016). The increase of the water potential in seeds caused by the soaking allows biochemical processes preparing the seed for germination to initiate: Mobilisation of energy and nutrients through the activity of amylases and other metabolic enzymes, and repair of cellular damage that occurred during storage of the seed (DNA, membranes, organelles, redox balances). This water-induced state of “readiness” for germination is maintained after the seeds have been dried, and phenotypically hydropriming is observed as the shortening of the time needed for the seeds to emerge after sowing.

As reviewed by Harris (2006), shortening of the time to emerge is critical to crop establishment, particularly in dry and hot areas since pre-emerged seedlings are especially susceptible to drought and heat (upper soil temperatures in Sahel may easily exceed 45°C). In addition, the risk of sun-mediated hardening of the soil surface (formation of surface crusts preventing seedlings from emerging) increases with the time needed for emergence.

Thus, the overall finding in the present study of a strong effect of hydropriming being evident in the most solar-exposed and dry zone is in full agreement with existing theory of crop physiology and seed hydropriming. However, it is still somewhat surprising that the observed effect declines to zero (or even less) in the more humid and central zone, within a distance of less than 200 km. We cannot exclude that some statistical variation contributes to this result, since we have only 16 observations in each zone. However, a clear difference between the two zones is evident.

Perspectives

Pearl millet is the dominant crop in the Northern zone of Burkina Faso, and the previous results from similar areas of Sahel (Aune and Ousman, 2011; Aune et al., 2012; Jidda and Anaso, 2017) together with the results presented here strongly encourage a participatory approach with farmers of millet in Northern Burkina Faso in order to stimulate uptake of this inexpensive and simple technology. Based on the experience from the present study, we expect the more flexible hydropriming protocol described to be appreciated by farmers as both technically feasible and as being in a good compliance with the organizing of field work in general. A participatory research approach could focus on testing hydropriming using farmers own seeds (in the present study, one large seed sample was tested per year on all fields). Similarly, with regard to management of the crop (ploughing, sowing, fertilization, weeding, etc.), farmers own practice could be followed in order to obtain results as close to the real-life situation as possible.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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