

## Abiotic Stresses Tolerance and Nutrients Contents in Groundnut, Pearl Millet and Sorghum Mini Core Germplasm for Food and Nutrition Security

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Groundnut, pearl millet and sorghum germplasm were investigated to identify new sources of tolerance to low phosphorus (LP) and/or drought stress (WS) and to assess genotypic variation for iron (Fe) and zinc (Zn) contents. Experiments were conducted in lysimetre conditions in a randomized completely block design with 5 replications, 2 water and 2 phosphorus treatments. Genotypic variability was observed for morphoagronomic and nutrients traits investigated. Groundnut accessions ICG 3312, ICG 11855, ICG 10053, ICG 15232 and ICG 11088 revealed drought tolerant. The combined WS-LP effect (73%) was higher than individual WS (68%) and LP (49%) effects. LP significantly delayed heading and flowering dates, accessions IP1060, IP11405 and IP9000 (millet), and ISS1412, ISS2167, ISS376 and ISS738 (sorghum) showed less delay and LP tolerance. Fe and Zn contents under LP showed that accessions IP17775, IP5581, IP5153, IP1060, IP6517 and IP5438 of millet; ISS376, ISS1412, ISS2167, ISS242, ISS311 and ISS2151 of sorghum revealed high Fe and/or Zn concentrations.

**Key Words:** Crop improvement, Drought tolerance, Low phosphorus, Mini core collections, Nutrients contents

### Introduction

Sustainable agriculture and malnutrition challenges require the use of genotypes tolerant to abiotic stress and highly rich in micronutrients. Detailed evaluation and characterization of materials conserved in genebanks could lead to select these genotypes. Mini core collections of groundnut, pearl millet and sorghum (Upadhyaya *et al.*, 2002; Upadhyaya *et al.*, 2009; Upadhyaya *et al.*, 2011), representing diversity of global collections, are ideal material for extensive evaluation to select new crop varieties adapted to future conditions, improve productivity and reduce malnutrition. Several studies in India on pearl millet, sorghum and groundnut mini core collections under drought, soil nutrients deficiency, heat, salinity and/or photoperiod conditions contributed to select diverse sources of several traits used in breeding new and performant varieties (Upadhyaya *et al.*, 2001; Upadhyaya *et al.*, 2003; Upadhyaya *et al.*, 2008, Upadhyaya *et al.*, 2012; Yadav *et al.*, 2017; Kumar *et al.*, 2012). Accessions ICG 12625, ICG 442, ICG 2381, ICG 14710 and ICG 7963 of groundnut (Upadhyaya *et al.*, 2014), IP 4066, IP 9496 and IP 9426 of pearl millet (Yadav *et al.*, 2003), and IS 2205, IS 3946, IS 5094 and IS 12883 of sorghum (Upadhyaya *et al.*,

2009; Mohankumar *et al.*, 2013) were some of selected germplasm for release and/or used in breeding programs to improve productivity and nutrition quality in India. Climate shocks will likely have an overall negative effects on agricultural production in many African countries and regions, and this could lead to food insecurity and malnutrition exacerbation (IPCC, 2014). West Africa is known to be particularly vulnerable to climate change due to high climate variability, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change (Nelson *et al.*, 2009; Sultan and Gaetani, 2016). Pearl millet, sorghum and groundnut are most important crops for food security and nutrition in West African countries (Hausmann *et al.* 2011, Vigouroux *et al.*, 2011, Hamidou *et al.*, 2012, Hamidou *et al.*, 2013, Hamidou *et al.*, 2014.) In Sahelian areas of West African regions groundnut, pearl millet and sorghum cultivation play key roles in food and nutrition but abiotic stresses particularly drought, heat, low soil fertility and malnutrition are yield and nutritive quality limiting constraints. These stresses will become more severe in near future and require identification of genotypes tolerant to abiotic stresses and relevant traits useful in breeding programs for improving adaptation, production and/or nutrition

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quality of major crops cultivated in the Sahel (Sultan and Gaetani, 2016). Like in India, exploiting/investigating the mini core collections of groundnut, sorghum and pearl millet in Sahelian countries could lead to select genotypes tolerant to major abiotic stresses and highly rich in micronutrients for developing crop improvement strategies that favor adaptation to climate variability. This work aims to investigate response of groundnut, pearl millet and sorghum germplasm mini core collections (Upadhyaya *et al.*, 2002, 2009, 2011) to drought and low soil phosphorus stresses. The objectives were to (i) characterize these germplasms under drought and/or low phosphorus conditions for selecting high yielding genotypes, (ii) assess individual and combined effects of drought and low phosphorus stress on agronomic performance and nutrients content of the germplasm and (iii) identify tolerant genotypes and relevant traits for crop improvement.

### Material and Methods

Three experiments were conducted at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Sahelian Centre (ISC) in Sadoré (45 km south of Niamey, Niger, 13°N, 2°E) during 2015 and 2016. Climatic data (temperature, humidity and ET through class A pan evaporation) were recorded daily from a meteorological station located close to the experiments. In addition, the temperature and relative humidity of the air were collected from a temperature and relative humidity recorder (Gemini Tinytag Ultra 2 TGU-4500 Data logger Ltd, Chichester, UK) located in the crop canopy.

One hundred and six (106) germplasm including 60 accessions of groundnut mini core collection (Upadhyaya *et al.*, 2002), 25 accessions of pearl millet mini core collection (Upadhyaya *et al.*, 2011) and 21 landraces of sorghum (Table 1) were assessed during rainy and off-seasons in lysimetre tubes (25 cm diameter, 130cm height). The lysimetric system was well described in our previous works (Beggi *et al.*, 2014; Halilou *et al.*, 2015). The soil used to fill the lysimetre tubes was collected from the farm in Sadoré station. The characteristics of the soil are: pH-H<sub>2</sub>O (5.28), capacity of cation exchange (1.91 cmol+ kg<sup>-1</sup>), organic matter (0.22%), total nitrogen (204.3 mg-N kg<sup>-1</sup>), total phosphorus (26.25 mg-P kg<sup>-1</sup>), phosphorus bray1 (1.83 mg-P kg<sup>-1</sup>). Top soil (0-20cm) and deep soil (20-100cm) were collected separately from the farm. To mimic the field conditions, the lysimetre

tubes were filled with deep soil (100 cm height) followed by top soil (20 cm height). The upper 10 cm of the tubes was left empty to allow the application of a layer of anti-evaporation beads and for watering. Three seeds were sown by hand and seedlings were thinned to one plant per tube at 14 days after sowing (DAS). The experimental design was a randomized complete block design with 5 replications, 2 water regimes and 2 phosphorus treatments. The water regimes were a full irrigation (WW) until harvest and a drought stress (WS) imposed from flowering (50%) to maturity times. WS was an intermittent drought consisting of cycles of drying (irrigation interruption) and re-watering (1000mL of water per tube) when the majority of WS plants showed clear wilting symptoms (Hamidou *et al.*, 2012). Prior to imposing WS, the lysimetre tubes were water saturated, drained during 2 days to reach field capacity and the soil surface was covered with a 2cm thick layer of polyethylene beads to minimize soil evaporation (Ratnakumar *et al.*, 2009). The two phosphorus treatments were HP treatment consisting of applying 7.5 g DAP tube<sup>-1</sup> in a circle 2–3 cm around the seedling area after emergence and the LP treatment consisted of no application of phosphorus in the tubes but supply urea (3.45 g applied in two doses) to compensate nitrogen input from DAP applied in HP tubes. DAP and urea were used in these experiments because they are the common fertilizers used by Sahelian farmers. The phenology (Heading, flowering and maturity times), growth (height), total transpiration (TTW) and transpiration efficiency (TE), micronutrients content (Fe, Zn), yield and its components were some of parameters measured. For TE measurement, two plants were left per tube after thinning. The day before water stress imposition, one of 2 plants of each tube was harvested, dried at 70°C for 2 days and the initial biomass (IDM) was determined. During water stress period, transpiration was measured via a gravimetric procedure. Thus, lysimetre tubes were weighed regularly (twice per week). As there was no evaporation nor draining, the difference of consecutive lysimetre weights, plus water added after the previous weighing, was equivalent to the transpiration (Vadez *et al.*, 2011a). The total transpired water (TTW) of WW and WS plants was determined for each individual plant. At maturity, plant of each cylinder was harvested, dried at 70°C for 2 days for determining the final dry matter (FDM). So, TE was calculated as: TE = (FDM - mean IDM) /TTW. For the micronutrients (Fe, Zn) content

**Table 1. Names and origins of groundnut, pearl millet and sorghum germplasm. ISS N° = ICRISAT Niamey genebank sorghum accession number. RCA = République Centre Africaine**

No	Name	Groundnut germplasm			Pearl millet germplasm		Sorghum germplasm (landraces)		
		Origin	Name	origin	Name	Origin	Local Name	ISS No	Origin
1	ICG 6813	India	ICG 15233	Unknown	IP19629	Niger	Yarimawa	ISS 242	Nigeria
2	ICG 15232	Unknown	ICG 11855	Bolivia	IP5455	Niger	Acualé	ISS 309	NIGER
3	ICG 36	India	ICG 7897	Zimbabwe	IP5719	Nigeria	Zermou FDawa	ISS 311	NIGER
4	ICG 6201	Unknown	ICG 5494	Sudan	IP5964	Senegal	98-884	ISS 333	Mauritanie
5	ICG 7906	Zimbabwe	ICG 3240	Unknown	IP5869	Senegal	98-972	ISS 337	Mauritanie
6	ICG 6394	Zimbabwe	ICG 1415	Senegal	IP1060	India	Betakatchi	ISS 376	Tchad
7	ICG 5195	Kenya	ICG 7181	USA	IP6517	Mali	Méré Rafa	ISS 378	Tchad
8	ICG 10384	Argentina	ICG 9666	Mozambique	IP5581	Niger	Socomba Tiudawa	ISS 705	niger
9	ICG 11542	Korea	ICG 3775	India	IP17532	Togo	Socomba Gogueize	ISS 738	niger
10	ICG 10920	Peru	ICG 334	China	IP19415	Chad	El Baoura	ISS 784	niger
11	ICG 9842	Peru	ICG 1703	Bolivia	IP5298	Niger	Takanda Bagaroua	ISS 862	niger
12	ICG 3992	Uganda	ICG 9777	Mozambique	IP6113	Niger	Jadawa Meguizawa	ISS 885	niger
13	ICG 6407	Paraguay	ICG 9809	Tanzania	IP5957	Senegal	Gadiabablé	ISS 1148	Mali
14	ICG 1711	Unknown	ICG 6703	Senegal	IP6278	Mali	Dérebléni	ISS 1350	Mali
15	ICG 15234	Unknown	ICG 5475	Malaysia	IP9000	Niger	Gadiabakoumaba	ISS 1412	Mali
16	ICG 7969	India	ICG 405	Unknown	IP5438	Niger	Kaurari K19-1	ISS 2110	Niger
17	ICG 6022	Cuba	ICG 2773	India	IP5711	Nigeria	Kaura Mai Sauri-	ISS 2148	Niger
18	ICG 4527	Sudan	ICG 12276	India	IP11405	BFaso	Botsotsoia	ISS 2133	Niger
19	ICG 1142	Benin	ICG 3746	Brazil	IP5185	Niger	Kaurari	ISS 2137	Niger
20	ICG 163	Unknown	ICG 4746	Malawi	IP17775	Togo	Tantagaria	ISS 2151	Niger
21	ICG 10053	Nigeria	ICG 81	Unknown	IP6057	RCA	Karangui	ISS 2167	Niger
22	ICG 1399	Malawi	ICG 14475	Mexico	IP8540	India			
23	ICG 1274	Indonesia	ICG 1823	Tanzania	IP5407	Niger			
24	ICG 1487	USA	ICG 115	India	IP5153	Niger			
25	ICG 10890	Unknown	ICG 11088	Taiwan	IP5261	Niger			
26	ICG 4670	Israel	ICG 3312	Argentina					
27	ICG 6375	Unknown	ICG 118	India					
28	ICG 10554	Peru	ICG 12988	Nigeria					
29	ICG 11109	China	ICG 862	India					
30	ICG 4911	Sudan	ICG 3027	Uganda					

of pearl millet and sorghum seeds, it was determined with XRF machine (Nielson *et al.*, 1988).

## Results

### *Genotypic Variation in Response to Drought and/or Low Phosphorus Stress*

#### *Groundnut Germplasm*

Flowering and maturity dates recorded on the groundnut mini core subset ranged from 22 to 31 and 85 to 97 days after sowing (DAS) respectively which indicate large genotypic variation. ICG 6703, ICG 7181, ICG 3775, ICG 6407 and ICG 10890 were the top 5 earliest maturing accessions while ICG 3027, ICG 15234, ICG 3992, ICG 9777 and ICG 9842 were late maturing materials. Significant genotype and water treatment interaction (GxTrt) was observed on the total transpired water (TTW) from flowering to maturity. TTW increased significantly

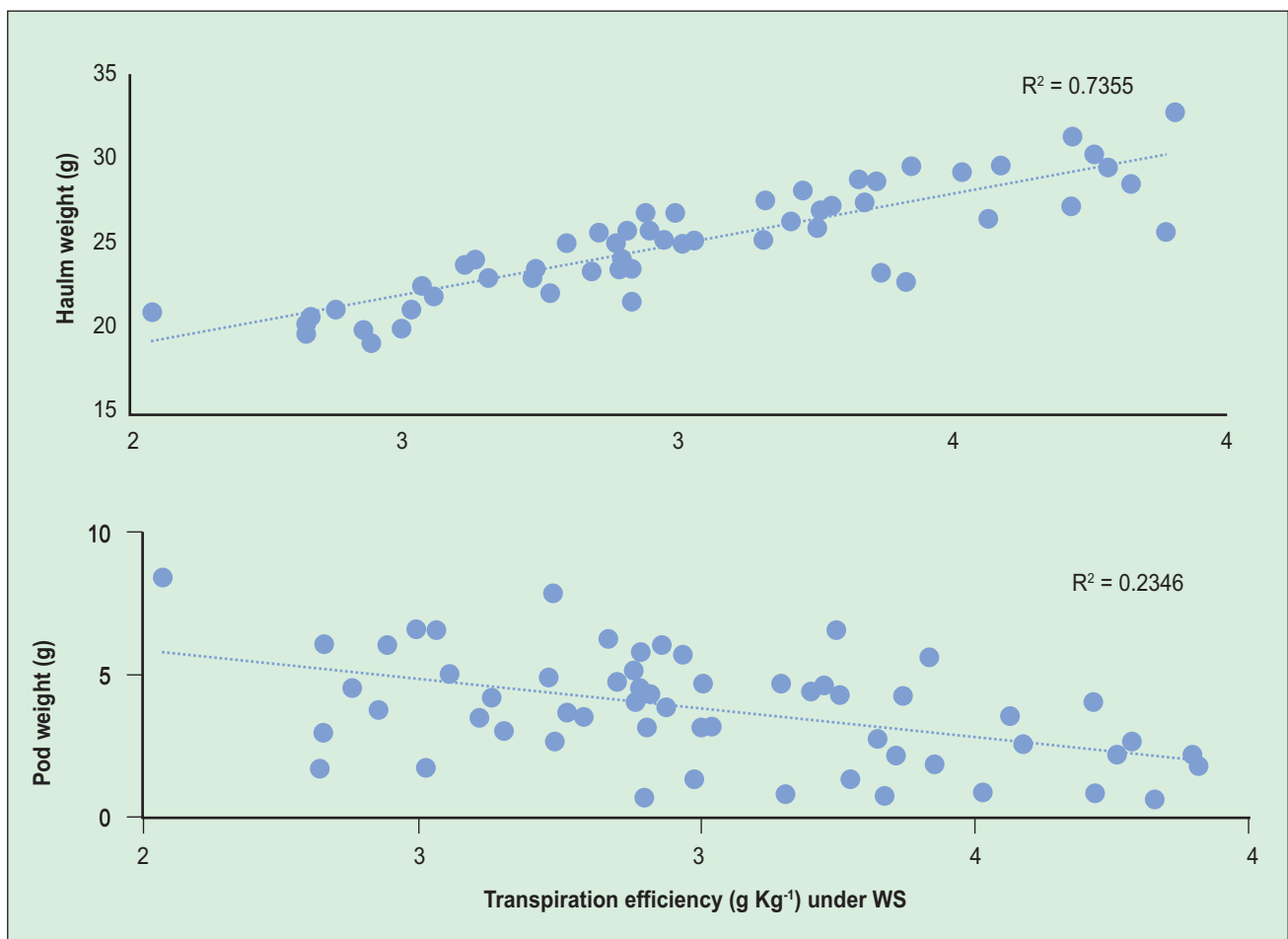
under WS compared to WW for all accessions except ICG 1399, ICG 5494, ICG 1274, ICG 11542 and ICG 1142 which showed significant transpiration decrease due to WS. ICG 7181, ICG 10384, ICG 7906, ICG 163 and ICG 1711 revealed the highest TTW increase. ICG 3312 and ICG 11088 showed high TTW under both WW and WS regimes. The highest TTW under WW was observed on ICG 3312, ICG 11088, ICG 3746, ICG 862, ICG 1274, ICG 11542 and ICG 1399 while ICG 7181, ICG 36, ICG 163, ICG 10384 and ICG 6703 showed the lowest TTW. Under WS, the genotypic variation on TTW revealed that ICG 11855, ICG 115, ICG 11088, ICG 15233 and ICG 3312 had highest TTW whereas ICG 1142, ICG 5494, ICG 9777, ICG 6703 and ICG 10890 had the lowest. Transpiration efficiency (TE) investigated under WW and WS showed significant ( $P<0.001$ ) effect of water regime and WS decreased TE up to 78%. Significant ( $P<0.001$ ) genotypic

variation was also observed under both WW and WS treatments, and ICG 9842, ICG 7181, ICG 3027, ICG 1274, ICG 14475 and ICG 4527 revealed high TE. Under WS, accessions with highest TE were ICG 3312 (1.85 g kg<sup>-1</sup>), ICG 11088 (1.61 g kg<sup>-1</sup>), ICG 13395 (1.50 g kg<sup>-1</sup>) and ICG 4670 (1.31 g kg<sup>-1</sup>) and revealed tolerant to drought stress. Genotypic variation was also observed on the branch number per plant, the pod weight per plant (Pwpt), haulm weight per plant (Hwpt) and seeds weight per plant (Swpt) which ranged respectively from 4 to 10, 3.4g to 19.4g, 25 g to 55g and 1.5g to 15g. WS imposed at flowering time decreased Hwpt (30%), Pwpt (68%) and Swpt(71%). Accessions ICG 3312, ICG 118, ICG 10053, ICG 15232 and ICG 11088 showed high pods and seeds weights under both WW and WS conditions. Linear regression performed showed high correlation ( $r^2 = 0.73$ ) between TE and Hwpt whereas low correlation ( $r^2 = 0.26$ ) was observed between Pwpt and TE under WS conditions (Fig. 1). Low phosphorus

stress (LP) decreased the pod number per plant (8%), the Pwpt (49%) and Hwpt (31%), the decrease due to combined WS and LP stress (WS-LP) was 16, 73 and 34% respectively. Under WS-LP conditions, ICG 4670 (4g) and ICG 3312 (8g) showed lowest pods weight while ICG 3399 (11g), ICG 115 (13g) and 3746 (18g) revealed the highest Pwpt.

#### *Pearl Millet Germplasm*

Phosphorus treatment has significant effect on tillering times, tillers number per plant, heading/booting time, flowering time and plant height of pearl millet accessions. Under HP, heading and flowering times ranged respectively from 43 to 65 DAS and 48 to 74 while under LP they ranged from 53 to 71 DAS and 57 to 75 DAS. LP delayed tillering, heading and flowering times while it decreased tillers number (30%) and plant height (22%). Heading and flowering delay due to LP ranged from 3 to 16 days and genotypic variation revealed that



**Fig. 1. Relationship between transpiration efficiency, pod and haulm weight per plant of groundnut germplasm under drought stress (WS) conditions**

IP1060, IP11405, IP19629, IP5185, IP5455 and IP9000 had 4 days of delay whereas IP5298, IP5869, IP5964 and IP8540 delayed for 13 to 16 days. LP stress decreased the total biomass and panicle weight up to 37 and 56% respectively. The highest biomass (70g) was observed on IP19629, IP5298, IP5581, IP5719 and IP5407 whereas IP11405, IP17532, IP17775, IP5957 and IP6057 showed the lowest (35g). The panicle weight under LP revealed highest values (15g) for IP1060, IP11405, IP5957, IP5964 and IP9000 and lowest values (2.6g) for IP5153, IP5185, IP5438, IP5711 and IP6517.

#### *Sorghum Germplasm*

Genetic diversity was observed on the phenology of sorghum accessions. Significant genotype and phosphorus treatment interaction was observed on heading, flowering and maturity times. Under HP and LP conditions heading time ranged respectively from 39 to 80 DAS and 44 to 82 DAS. Variation on flowering time was from 41 to 81 under HP and 46 to 87 DAS under LP whereas maturity time varied under HP and LP from 61 to 93 DAS and 60 to 107 DAS, respectively. Phosphorus deficiency (LP) had no significant effect on days to flowering and maturity in accessions ISS 1148, ISS 1412, ISS 2133, ISS 2167, ISS 376, ISS 705 and ISS 738 while it delayed flowering and maturity dates in ISS 2110, ISS 2151, ISS 242, ISS 309 and ISS 337. Significant ( $P < 0.001$ ) genotypic difference was observed also on total biomass, panicle weight per plant (pawpt) and Swpt under both HP and LP treatments. Under LP, ISS 337 (80.6g), ISS 2110 (80.7g), ISS 2133 (81.6g), ISS 2151 (86.5g), ISS 1350 (94.4g) and ISS 2137 (97.8g) showed the highest biomass, the highest pawpt observed on ISS 1350 (27.5g), ISS 1412 (33.7g), ISS 2133 (32.5g), ISS 2137 (40g), ISS 2148 (27.6g) and ISS 337 (27.2g) while the highest Swpt was observed on ISS 2110 (21.7g), ISS 1350 (22g), ISS 1412 (24.5g), ISS 2133 (24.6g), ISS 2137 (30.3g) and ISS 2167 (22.4g).

#### *Micronutrient Contents in Pearl Millet and Sorghum*

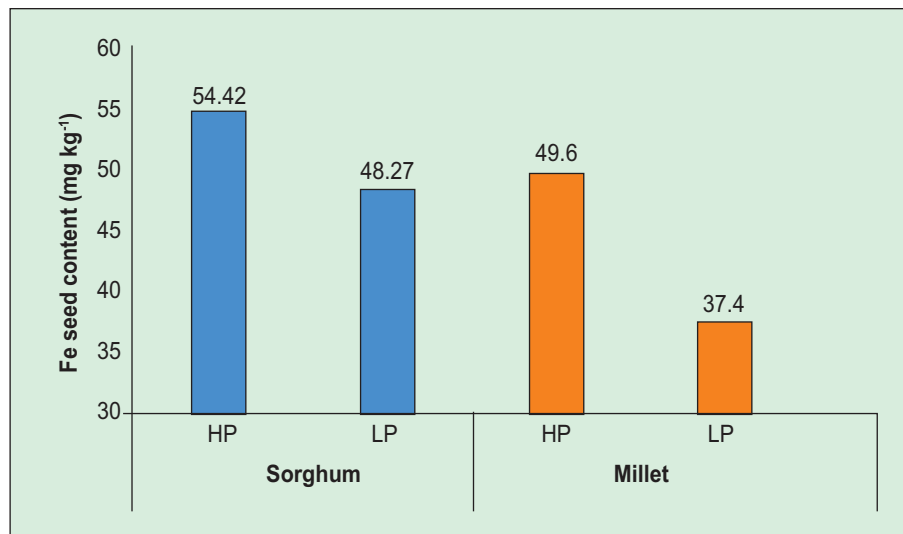
Determination of Iron (Fe) and zinc (Zn) in seeds revealed significant ( $P < 0.001$ ) phosphorus treatment effect on Fe content in both pearl millet and sorghum (Fig. 2) while for Zn content the effect was significant ( $P = 0.004$ ) only in sorghum. Fe decrease due to LP was 25 and 13% in pearl millet and sorghum, respectively, Zn decrease in sorghum was 11%. Genotypic variation in micronutrients contents showed that under HP conditions Fe content

varied from 30 to 72 mg kg<sup>-1</sup> in pearl millet, from 38 to 64 mg kg<sup>-1</sup> in sorghum while under LP treatment Fe content ranged from 27 to 57 mg kg<sup>-1</sup> in pearl millet and from 33 to 54 mg kg<sup>-1</sup> in sorghum. IP5261 (58 mg kg<sup>-1</sup>), IP5185 (63 mg kg<sup>-1</sup>), IP5964 (64 mg kg<sup>-1</sup>), IP17775 (66 mg kg<sup>-1</sup>) and IP9000 (72 mg kg<sup>-1</sup>) for pearl millet and ISS 885 (56 mg kg<sup>-1</sup>), ISS 1148 (60 mg kg<sup>-1</sup>), ISS 2110 (61 mg kg<sup>-1</sup>), ISS 784 (61 mg kg<sup>-1</sup>) and ISS 242 (64 mg kg<sup>-1</sup>) for sorghum revealed the highest Fe concentrations. As for Zn content, the variation was from 38 to 96 mg kg<sup>-1</sup> in millet and from 41 to 72 mg kg<sup>-1</sup> in sorghum under HP while under LP it ranged from 47 to 94 mg kg<sup>-1</sup> in pearl millet and from 38 to 75 mg kg<sup>-1</sup> in sorghum. Accessions IP17775 (49 mg kg<sup>-1</sup>), IP17532 (51 mg kg<sup>-1</sup>), IP5581 (51 mg kg<sup>-1</sup>) and IP5153 (57 mg kg<sup>-1</sup>) for pearl millet and ISS 333 (50 mg kg<sup>-1</sup>), ISS 376 (52 mg kg<sup>-1</sup>), ISS 311 (53 mg kg<sup>-1</sup>) and ISS 1412 (54 mg kg<sup>-1</sup>) for sorghum revealed the highest Fe contents under LP conditions. Highest Zn contents in pearl millet under LP were observed on IP1060 (77 mg kg<sup>-1</sup>), IP6517 (82 mg kg<sup>-1</sup>), IP5438 (84 mg kg<sup>-1</sup>) and IP17775 (94 mg kg<sup>-1</sup>) and in sorghum on ISS 2167 (54 mg kg<sup>-1</sup>), ISS 242 (54 mg kg<sup>-1</sup>), ISS 311 (54 mg kg<sup>-1</sup>) and ISS 2151 (75 mg kg<sup>-1</sup>).

#### **Discussion**

##### ***Drought and Low Phosphorus Tolerance in Groundnut***

The genetic variability observed on TTW suggests different water requirement and use among the groundnut accessions. In response to drought stress, some accessions like ICG 7181, ICG 10384, ICG 7906, ICG 163 and ICG 1711 increased TTW while others like ICG 1399, ICG 5494, ICG 1274, ICG 11542 and ICG 1142 decreased TTW. This suggests different mechanism of response to drought. Indeed, TTW increase under drought stress indicates an increase of water lost while TTW decrease shows a reduction of water lost. Jayant *et al.*, 2015 reported that under drought stress, prevention of water loss through aerial parts of the plant is considered as one of the most important mechanism to avoid drought. Transpiration reduction in response to drought led to dehydration avoidance due to lower stomatal conductance in order to conserve water (Mafakheri *et al.*, 2012). Accessions ICG 11855, ICG 115, ICG 11088, ICG 15233 and ICG 3312 showed the highest TTW under WS suggesting high stomatal conductance and intensive roots elongation to deeper part of the soil profile. High



**Fig. 2. Iron (Fe) content (mg kg<sup>-1</sup>) in pearl millet and sorghum seeds under high phosphorus (HP) and low Phosphorus (LP) conditions**

transpiration under WS could reveal a drought tolerance mechanism by maintaining the turgor through osmotic adjustment, increase cell elasticity and decrease cell size as well as desiccation tolerance by protoplasmic resistance (Nemeskeri *et al.*, 2012; Jacqueline *et al.*, 2016).

The genotypic variation observed in TE revealed the highest TE on ICG 3312 (1.85 g kg<sup>-1</sup>), ICG 11088 (1.61 g kg<sup>-1</sup>), ICG 13395 (1.50 g kg<sup>-1</sup>) and ICG 4670 (1.31 g kg<sup>-1</sup>) under WS. The TE, calculated as dry matter produced per kg of water transpired, was highly correlated ( $r^2 = 0.73$ ) to haulm weight under WS suggesting that canopy development contributed to TE. This corroborates previous works which reported that high TE under drought stress could be explained by specific leaf area, high roots dry matter and/or chlorophyll content (Puangbut *et al.*, 2009a, Puangbut *et al.*, 2009b). Drought stress decreased Pwpt and Swpt, the genotypic variation observed revealed that accessions ICG 3312, ICG 11855, ICG 10053, ICG 15232 and ICG 11088 showed high Pwpt and Swpt under both WW and WS conditions. These accessions revealed high yielding and drought tolerant. They could be recommended for cultivation under rainfed environments and could be donors in groundnut improving programs for drought adaptation and productivity.

Low phosphorus (LP) stress had lower effect on Pwpt than WS. However, Pwpt decrease under WS-LP stress (73%) was higher than the decrease under individual WS (68%) and LP (49%) stress. ICG 3312

showed high Pwpt under WS and low Pwpt under WS-LP stress suggesting it was tolerant to drought but sensitive to combined WS-LP. These findings could indicate that phosphorus (P) is much critical in pods productivity under drought stress in groundnut. Authors reported that P nutrient improved root traits to enhance tolerance to water stress and reduce yield loss in chickpea (Jin *et al.*, 2012). ICG 115 which showed high TTW under WS conditions revealed high Pwpt under WS-LP stress suggesting a mechanism of roots elongation in deeper part of soil for exploring water and nutrients (P) for tolerance to WS-LP.

#### **Low P Response and Nutrients Content in Pearl Millet and Sorghum**

In pearl millet, LP stress induced significant delay in heading and flowering dates. However, a genetic variability was observed indicating that accessions IP1060, IP11405, IP19629, IP5185, IP5455 and IP9000 showed 4 days of delay whereas the delay was up to 16 days for IP5298, IP5869, IP5964 and IP8540. Beggi *et al.* (2014) reported a booting and flowering delay up to 2 weeks due to LP stress in pearl millet. The genetic diversity observed could be exploited in breeding for LP tolerance in pearl millet. Phenological delay has often been reported as an adaptive response of annual plants to P deficiency because it increases the duration of nutrient uptake (Nord and Lynch, 2008). However, under Sahelian conditions where mid-season and terminal drought occur frequently, a flowering delay in pearl millet would indeed increase the risk of the plant

encountering water deficient conditions. Our findings showed a biomass and panicle weight decrease due to LP stress. Accessions IP1060, IP11405 and IP9000 showed short delay and high panicle weight suggesting that no significant sensitivity of flowering time to LP stress could have benefits in grains productivity. In previous work (Beggi *et al.*, 2014) we found high correlations between flowering delay and grains yield in pearl millet and had also observed that genotypes with short flowering delay under LP stress showed less decrease of seeds size. Thus, IP1060, IP11405 and IP9000 revealed interesting materials potentially useful for low soil P conditions and in breeding program for improving tolerance to LP stress.

Low soil P affected also the micronutrients content of seed in pearl millet. Fe content decreased up to 25% while the effect was not significant for Zn content. Large genotypic variation was observed on Fe content which ranged from 27 to 57 mg kg<sup>-1</sup>. Previous studies reported also a wide variability for Fe in pearl millet (Rai *et al.*, 2008; Rai *et al.*, 2012; Rai *et al.*, 2014; Elad *et al.*, 2015; Yadav *et al.*, 2016; Yadav *et al.*, 2017). With high Fe concentration, IP5261 (58 mg kg<sup>-1</sup>), IP5185 (63 mg kg<sup>-1</sup>), IP5964 (64 mg kg<sup>-1</sup>), IP17775 (66 mg kg<sup>-1</sup>) and IP9000 (72 mg kg<sup>-1</sup>) revealed new sources of high Fe concentration and could be useful for biofortification program in pearl millet. Fe concentration of those lines was less high than in IP 17602 (121 mg kg<sup>-1</sup>), IP 17673 (109 mg kg<sup>-1</sup>) and IP 9404 (108 mg kg<sup>-1</sup>) reported by Yadav *et al.* (2017). This difference could be explained by the soil type and/or soil nutrient contents. Accessions IP17775 (49 mg kg<sup>-1</sup>), IP17532 (51 mg kg<sup>-1</sup>), IP5581 (51 mg kg<sup>-1</sup>) and IP5153 (57 mg kg<sup>-1</sup>) showed high Fe content under LP conditions. These accessions revealed promising materials for low soil P environments. Highest Zn contents under LP were observed on IP1060 (77 mg kg<sup>-1</sup>), IP6517 (82 mg kg<sup>-1</sup>), IP5438 (84 mg kg<sup>-1</sup>) and IP17775 (94 mg kg<sup>-1</sup>). Interestingly, IP17775 showed high Fe and Zn contents under LP stress suggesting it could contribute in food nutrition to combat Fe and Zn deficiency (Issoufou *et al.*, 2013; Jakunti *et al.*, 2016).

In Sorghum, large variation in phenology was observed. The flowering time varied from 41 to 81 DAS under HP and 46 to 87 DAS under LP whereas maturity time varied under HP and LP respectively from 61 to 93 DAS and 60 to 107 DAS. LP stress induced flowering and maturity delay on some accessions while it had no significant effect on others, which indicates genotypic

variation in response to soil P deficiency. Delayed heading and flowering in west African sorghum panel under LP stress was reported previously (Leiser *et al.*, 2014). The large delay in flowering under LP conditions indicates important growth differences which should permit a genetic study of adaptation to P-limited conditions. The absence of significant effect of LP stress on phenological traits of ISS 1148, ISS 1412, ISS 2133, ISS 2167, ISS 376, ISS 705 and ISS 738 could suggest tolerance to LP. Additional studies are required for confirmation and understanding the mechanisms underlying the non-significant effect of LP stress on the phenology plasticity of these accessions. Under LP conditions, ISS 333 (50 mg kg<sup>-1</sup>), ISS 376 (52 mg kg<sup>-1</sup>), ISS 311 (53 mg kg<sup>-1</sup>) and ISS 1412 (54 mg kg<sup>-1</sup>) showed high Fe content while high Zn concentration was observed on ISS 2167 (54 mg kg<sup>-1</sup>), ISS 242 (54 mg kg<sup>-1</sup>), ISS 311 (54 mg kg<sup>-1</sup>) and ISS 2151 (75 mg kg<sup>-1</sup>). ISS 311 with high Fe and Zn contents under LP stress could contribute in food nutrition to alleviate Fe and Zn deficiency but bioavailability of these micronutrients must be confirmed.

## References

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