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REGISTRATION

Cultivar

'Amina', 'Dioufissa', and 'Haby': Heat tolerant durum wheat cultivars adapted to the Senegal River Basin

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Abstract

Senegalese are consumers of pasta, couscous, and other semolina products, which are obtained from durum wheat [*Triticum turgidum* L. *durum* (Desf)] grain imports. The Senegal River farming system offers a short dry winter season (harmattan) that is suitable for the cultivation of heat tolerant durum wheat. Hence, delivering super-early high-yielding and heat tolerant durum cultivars was a major goal in this region. 'Amina' (Reg. no. CV-1217, PI 708102), 'Dioufissa' (Reg. no. CV-1218, PI 708103), and 'Haby' (Reg. no. CV-1219, PI 708104) are durum wheat cultivars released in 2020 for cultivation in Senegal and West Africa after 4 years of multi-locations testing. All three are elite lines field-selected at the research farms of Fanaye in Senegal and Kaedi in Mauritania, both of which are located along the Senegal River. These cultivars are released jointly by the Senegalese Institute for Agricultural Research (ISRA), National Center for the Agricultural Research and development (CNRADA) in Mauritania, and the International Center for the Agricultural Research in the Dry Areas (ICARDA) in Morocco because of their adaptation to hot irrigated conditions, early maturity, higher grain yield and good grain quality.

1 | INTRODUCTION

Wheat (*Triticum aestivum* L. and *T. turgidum* L. *durum* Desf.; bread and durum, respectively) is the second most consumed cereal in Senegal after rice (*Oryza sativa* L.). Because of its national importance, rice is the predominant crop along the Senegal River, where some 60,000 ha are cultivated each year according to FAO in two consecutive seasons: the dry irrigated season is planted in late March and harvested in early June, and the wet rainy season is planted in July and harvested

in late October. This leaves a short 100–110 days' window during harmattan in which wheat can be cultivated under gravity irrigation, with planting occurring in November and harvest in March. This period is not suitable for rice cultivation because of the relatively low (16˚C) night temperatures, while heat-tolerant wheat cultivars can thrive despite daily maximum temperatures always exceeding 30˚C from planting to harvest. As of December 2014, only 1 hectare of wheat was cultivated in Senegal at the research farm of Fanaye. In December 2024, 10 years later, the Senegalese government planned to produce 3000 ha of durum wheat in Senegal thanks to the introduction of heat-tolerant cultivars described herein due to their previous performance in multi-environment field trials along the Senegal River Basin (Sall, Bassi, et al., 2018; Sall, Kabbaj, et al., 2018).

An initial attempt in 2012 at durum wheat cultivation was the introduction of 'Bani Suef 5', a cultivar of CIMMYT's origin released in Egypt in 2008 (Bado et al., 2010). However, this high yielding cultivar lacked the earliness required to vacate the fields before rice planting, so its adoption never reached scale. Hence, a priority for the new set of introductions was to impose strong selection pressure for earliness, combined with heat tolerance and high yield. A vast set of elite germplasm introductions from many breeding programs were tested in this region by an international team of scientists from Swedish University of Agricultural Sciences (SLU), International Center for Agricultural Research in the Dry Areas (ICARDA), Senegalese Institute for Agricultural Research (ISRA), and National Center for Agricultural Research and Development (CNRADA) in several field trials (Alahmad et al., 2020; Bassi & Nachit, 2019; El Haddad et al., 2021; Mazzucotelli et al., 2020; Sall, Kabbaj, et al., 2018).The objective of this paper is to report the official release in 2020 in Senegal of the three durum wheat cultivars, 'Amina' (Reg. no. CV-1217, PI 708102), 'Dioufissa' (Reg. no. CV-1218, PI 708103), 'and Haby' (Reg. no. CV-1219, PI 708104), and their further acceptance for cultivation in all West Africa.

Core Ideas

- Delivery of super-early, high-yielding, heat-tolerant durum cultivars is a major goal in Senegal River Basin.
- High-yielding cultivars adapted to hot irrigated conditions, mature early, and with good grain quality are released.
- We announce the official release in Senegal of 'Amina', 'Dioufissa', and 'Haby'.

2 | METHODS

2.1 | Parentage and selection history of Amina, Dioufissa, and Haby

Amina is named after the daughter of the Senegalese breeder who registered it. Its pedigree is 'Korifla' (CIMMYT)/Ae.SpeltoidesSyr//'Loukos' (ICARDA) representing a top cross between an old CIMMYT elite, Korifla, and a wild relative *Aegilops speltoides* collected in Syria, then top crossed to an elite ICARDA line, Loukos. Its selection history is ICDJMC04-006-BThL(Bulksel)-0sTh-0wTh-0sTh-6wTh-0sTh-0MCH-0MCH-0FAN. The cross-code ICD stands for ICARDA Durum; J, genebank; MC, Mediterranean climates; 04, indicates it was performed in 2004; and 006 indicates it was the sixth cross performed that year. BThL(Bulksel) is a code used to identify wide crosses made by the genebank of ICARDA. The selection history of Amina indicates bulking of F_1 in the summer season of Tel Hadya (0sTh) in Aleppo (Syria), bulking of F_2 in winter season in Tel Hadya (0wTh), bulking of F_3 in summer season in Tel Hadya (0sTh), harvesting by pedigree of the F_4 plant no. 6 in winter Tel Hadya (6wTh), followed by bulking F_5 in summer at the same station, and then yield trialed twice as bulks in Marchouch (MCH) in Morocco as $F_{5:6}$ and $F_{5:7}$. Finally seed was shipped to Senegal where one more bulking was done in Fanaye (FAN) to $F_{5:8}$ during the winter seasons, followed by four additional years of field trials before release. A single spike purification step was performed before release to generate F_{11}-derived homogeneous commercial seed.

Dioufissa is named after the Fanaye station manager who has recently retired. Its full pedigree is Ouasloukos1/5/Ainzen1/4/Bezaizshf//SD19539/'Waha' (ICARDA)/3/'Gidara 2'. It is a composite cross among several ICARDA's elites and two released cultivars: Waha released in Algeria in 1984 and still cultivated today, and Gidara 2 released in Turkey in 2004 (Bassi et al., 2019). Its selection history is ICD03-0342-BLMSD-0AP-2AP-0Tr-6AP-0Tr-3AP-0Tr-4AP-0THT-0AP -0TR-0FAN. ICD stands for ICARDA Durum; 03 indicates 2003, the year when the cross was made; number 0342 is the cross identifier; BLMSD indicates the cross scope for Mediterranean semi-arid conditions. The F_1 seeds were bulk harvested in Aleppo (0AP). The F_2 plant no. 2 was harvested by pedigree in Aleppo (2AP), then bulking of F_3 occurred in Terbol, Lebanon (0Tr). The sixth F_4 plant was selected by pedigree in Aleppo (6AP). The same process was then repeated twice: bulking of F_5 in Terbol (0Tr), then third F_6 plant by pedigree in Aleppo (3AP), and again bulking of F_7 in Terbol (0Tr), then fourth F_8 plant by pedigree in Aleppo (4AP). The F_9 seed was bulked in Tel Hadya (0THT), and yield trials with bulking were performed in Aleppo as $F_{9:10}$ (0AP) and then Terbol as $F_{9:11}$ (0TR). Finally, $F_{9:12}$ seed was sent to Fanaye for testing and multi-year trials (0FAN). A single spike purification step was performed before release to generate F_{14}-derived homogeneous commercial seed.

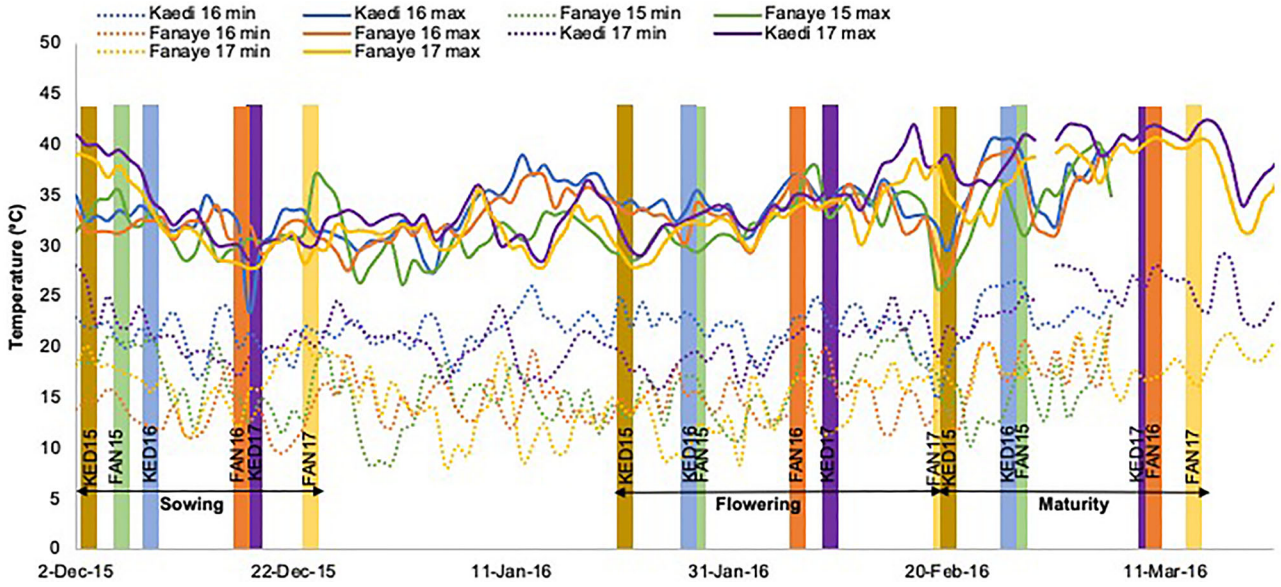

FIGURE 1 Maximum and minimum temperatures during 2014–2015, 2015–2016, and 2016–2017 seasons at Fanaye and Kaedi with indications on the date of planting, average flowering, and average maturity dates. Temperature data for Kaedi 2014–2015 were not available.

Haby is named after the daughter of the Mauritanian breeder who registered it. Its pedigree is 'Omrabi 5' (ICARDA)/T.dicoccoidesAleppoCol//'Cham1' representing a top cross between an old ICARDA elite Omrabi 5 and a wild relative *Triticum diccoides* collected in Aleppo (Syria), then top crossed to an old Syrian cultivar, Cham1. Its selection history is ICDJMC04-010-BThL(Bulksel)-0sTh-0wTh-0sTh-3wTh-0sTh-0MCH-0MCH-0FAN. As before, the cross-code ICD stands for ICARDA Durum; J, genebank; MC, Mediterranean climates; 04, indicates it was performed in 2004; and 010 indicates it was the 10th cross performed that year. BThL(Bulksel) is a code used to identify wide crosses made by the genebank of ICARDA. The selection history indicates bulking of F_1 in the summer season of Tel Hadya (0sTh) in Aleppo (Syria), bulking of F_2 in winter season in Tel Hadya (0wTh), bulking of F_3 in summer season in Tel Hadya (0sTh), harvesting by pedigree of the F_4 plant no. 3 in winter Tel Hadya (3wTh), followed by bulking F_5 in summer at the same station, and then yield trialed twice as bulks in Marchouch (MCH) in Morocco as $F_{5:6}$ and $F_{5:7}$. Finally, seed was shipped to Senegal where one more bulking was done in Fanaye (FAN) to $F_{5:8}$ during the winter seasons, followed by an additional 4 years of field trials before release. A single spike purification step was performed before release to generate F_{11}-derived homogeneous commercial seed.

2.2 | Evaluation of agronomic, DUS, and grain quality traits

A set of 24 durum wheat elite lines were selected from two ICARDA international nurseries, the First Afrique du Nord trials (AfN) and the 38th International Durum Yield Trials (IDYT38), and from CIMMYT 46th International Durum Yield Nurseries (IDYN46). Among these entries were the three cultivars presented here (Sall, Kabbaj, et al., 2018). Multi-years and multi-locations trials were carried out at two irrigated Savanah-type experimental stations: Fanaye, Senegal (FAN:16°53′ N; 15°53′ W) and Kaedi, Mauritania (KED: 16°14′ N; 13°46′ W) during winter seasons 2014–2015, 2015–2016, and 2016–2017. All experiments used the alpha lattice design with six sub-blocks of size four repeated two times. The genotypes were grown in experimental plots of 7.5 m^2 at a sowing density of 120 kg ha^{-1}. A total of 150 kg of nitrogen was provided in three equal split applications, while 50 kg of phosphorus and potassium were provided as base fertilization before planting. A complete description of agronomic data recording and analysis was previously presented in Sall, Kabbaj, et al. (2018). Briefly, the date to heading and maturity, plant height, 1000-kernel weight, and grain yield were recorded.

In season 2017–2018, the three preferred elites were submitted for an additional 2 years of testing to the National Advisory Council for Seeds and Plants (CNCSP). The national catalogue evaluation was conducted at Fanaye, where Amina, Haby, and Dioufissa cultivars were characterized for distinctness, uniformity, and stability (DUS) during two seasons, following testing guidelines of the International Union for the Protection of New Varieties of Plants (UPOV, 2012) for scoring of characters, the period of observations and methods used. In parallel, during seasons 2017–2018 and 2018–2019, these lines were also evaluated at three farmers' fields to validate their commercial value.

TABLE 1 Grain yield across sites (Fanaye, Kaedi, Pendao, Razel) and over years (2017, 2018, 2019) of the three durum cultivars and the percentage of superiority to the check cultivar Bani Suef 5.

Cultivar	Fanaye17	Kaedi17	Fanaye18	Kaedi18	Mean	% of superiority
	kg ha^{-1}					
Station						
Amina	3761	3357	3838	3267	3556	26
Haby	3844	3867	3768	4253	3933	41
Dioufissa	2916	3640	3733	3200	3372	19
Farmer's field						
	Fanaye18	**Fanaye19**	**Pendao19**	**Razel19**	**Mean**	
Amina	3356	3272	3943	3768	3585	14
Haby	4021	4189	4293	3765	4067	30
Dioufissa	3216	3301	4383	3699	3650	16

TABLE 2 Agronomic and technological comparison of the three durum cultivars with the check cultivar Bani Suef 5.

Traits	Amina	Haby	Dioufissa	Bani Suef 5
Days to heading	59	57	55	59
Days to maturity	92	91	89	92
Plant height (cm)	76	72	70	71
1000 kernel weight (g)	40	40	38	37
Grain yield (t ha^{-1})	3.56	3.93	3.37	2.82
Potential grain yield (t ha^{-1})	3.84	4.25	3.73	3.99
Protein (%)	13	14	13	15
Falling number (s)	357	350	393	430
Grain volume weight (kg hl^{-1})	82	81	81	83
Dry gluten (%)	10	11	9	11
Gluten index (%)	5	39	9	48
Gluten humid (%)	31	33	30	34

In addition to the field testing for DUS, all three cultivars were also evaluated for grain quality. Grain samples (500 g for each cultivar) were collected from the 2019 harvest and evaluation was conducted at the wheat quality laboratory of OLAM Senegal Mill. Quality analyses were performed according to American Association of Cereal Chemists international protocols (AACC, 2008). Starch breakdown due to alpha amylase enzyme activity was measured by the falling number test (Perten, 1964). Grain protein content was analyzed using a Chopin Technologies Infraneo near-infrared spectroscopy. The 1000-kernel weight was determined by counting 200 randomly selected grains on a Numigral counter followed by weighting on a precision scale. Whole grain flour samples were obtained with a whole mill grinder (Bastak) and were used to determine the gluten index, dry and wet gluten. The complete set of field and quality testing was used to determine the official release of these three cultivars.

3 | CHARACTERISTICS

3.1 | Grain yield performances under heat affected environment

Along the Senegal River Basin, maximum daily temperatures are constantly above 30°C throughout the wheat growing cycle (Figure 1) in the harmattan season. During all growing seasons at the Senegalese station, average minimum night temperatures oscillated between 14°C and 18°C, while in Mauritanian station the minimum night temperatures rarely descended below 22°C. Maximum day temperatures ranged between 30°C and 37°C at the two sites.

Here, Amina, Haby, and Dioufissa cultivars were able to withstand the high temperatures of West African drylands with yields above 3 t ha^{-1} of grain at farmers' field, in a short cycle of about 90 days between planting and harvesting. Haby was the top yielding cultivar across sites and over years (Table 1) at both station and farmers' fields with average grain yield up to 3.93 and 4.07 t ha^{-1}, respectively. At the field station, this line outperformed the check cultivar Bani Suef 5 with yield superiority of 41% over years and sites. Meanwhile, Amina and Dioufissa had respectively 26% and 19% of superiority over the reference check over years and across sites along the Senegal River. At farmers' field, this superiority was also confirmed with Haby reaching 30% yield superiority, Amina and Dioufissa had 14% and 16% of superiority, respectively. The cultivars Amina and Haby were the best performers when also considering the Mauritanian station of Kaedi (Sall, Kabbaj, et al., 2018), where stronger heat stress occurs.

TABLE 3 Botanical descriptions of Amina, Haby, and Dioufissa along with that of Bani Suef 5 (reference cultivar from Egypt).

Traits	Amina	Haby	Dioufissa	Bani Suef 5
Plant: growth habit	Erect	Erect	Erect	Semi-erect
Plant: length	Long	Medium	Medium	Short
Time of emergence	Medium	Medium	Early	Late
Flag leaf: glaucosity of sheath	Strong	Medium	Strong	Strong
Flag leaf: glaucosity of lower side of leaf blade	Medium	Absent	Medium	Strong
Culm: glaucosity of neck	Strong	Weak	Medium	Medium
Ear: glaucosity	Medium	Weak	Weak	Medium
Lower glume: hairiness of external surface	Absent	Present	Absent	Absent
Ear: length (excluding awns)	Short	Long	Short	Short
Ear: length of awns at tip relative to length of ear	Longer	Longer	Longer	Longer
Ear: coloration	White	White	White	White
Awn: color	White	Dark purple	Dark purple	White

3.2 | Agronomic and technological comparison

The agronomic and technological comparison of Amina, Haby, and Dioufissa cultivars with the check are provided in Table 2. The earliest maturing cultivar Dioufissa matured just after 89 days, 3 days before the reference check. Early maturing is a key trait to be considered in the short winter season occurring along the Senegal River. In fact, phenology traits significantly affected grain yield (Sall, Bassi, et al., 2018), thereby indicating their decisive role in performance under heat stress. The earliest genotypes performed better overall supporting assertions from Maccaferri et al. (2011) and Lopes et al. (2014). This is probably due to their ability to escape the hottest days during heading and extend their grain filling period.

Amina was taller than the check cultivar, which is a positive trait since local farmer rely on harvested straw to feed their livestock. All three cultivars showed high performances for 1000-kernel weight, an important trait for durum wheat as it contributes to grain yield and to overall semolina yield. Baril (1992) and Mohammadi et al. (2012) concluded that genotypes with larger kernels tend to yield better when grown under irrigation. In addition, the capacity of maintaining good grain weight after exposure to heat during the grain filling period is commonly regarded as a good indication of tolerance to this stress (Atefeh et al., 2011; Gupta et al., 2001). Also, grain specific weight for all three exceeded the minimum requirement (76 kg/hL) indicating good density of the grain.

Amina, Haby, and Dioufissa had grain protein percentage corresponding to the first quality class (13%–14%). The falling number of the three cultivars are above the industry threshold of 300 s (Campbell et al., 2021) indicating that they meet the industrial requirements. Since these are durum wheat cultivars, it is as expected that Amina and Dioufissa have weak gluten, while Haby reached normal gluten index (39%).

The high grain yield, 1000- kernel weight, grain specific weight, grain protein content, falling number, and tolerance to heat of Amina, Haby, and Dioufissa were the primary justifications for release.

3.3 | Morphological characteristics

Considering several morphological traits, Amina, Haby, and Dioufissa are very different to each other and to the reference cultivar Bani Suef 5 (Table 3). They are clearly different to the reference cultivars regarding plant growth habit and height. In fact, all of them are erected and taller than the semi-erect, short reference cultivar Bani Suef 5. The reference cultivar has the strongest glaucosity of lower side of leaf blade (Figure 2), while Amina is easily recognized with its strong glaucosity on the neck. Haby is distinguished by the long ear, the presence of hairiness of external surface on the lower glume (Figure 2) and its weak glaucosity. Dioufissa is mainly characterized by its earliness.

4 | CONCLUSION

Amina, Haby, and Dioufissa are well adapted to the hot irrigated conditions of the Senegal River Basin. These durum cultivars generated high grain yield exceeding 4 t ha^{-1}, with large kernels, in a short growth cycle of less than 92 days between planting and harvest. The earliness of these cultivars allows crop rotation with rice and avoids extreme heat occurring at the end of the growing cycle. These new cultivars are ideal germplasm sources for heat tolerance breeding and their seeds already reached farmers along the Senegal River Basin and beyond. The area of possible expansion of wheat cultivation corresponds to the 200,000 ha currently grown as rice. Multiplying this area by the average yield of 3 t ha^{-1},

FIGURE 2 Morphological characteristics differences between 'Amina', 'Haby', and 'Dioufissa' along with that of 'Bani Suef 5' (reference cultivar from Egypt).

reached by the three cultivars, suggests the potential of producing 600,000 t of durum wheat grains in sub-Saharan Africa with a potentially life-changing impact.

Following their release, 1000 spikes-to-row each were planted in Fanaye to generate Generation 1 (G1) in 2021, which was certified by Division des Semences (DISEM). These cultivars have now been advanced to G2 and currently G3 and following generations for commercial use.

5 | AVAILABILITY

The Senegalese Institute for Agricultural Research (ISRA) maintain and produce breeder and foundation seeds of Amina, Haby, and Dioufissa. Pure seeds of these cultivars are also available at the International Centre for Agricultural Research in the Dry Areas (ICARDA) in Rabat (Morocco). Requests for seed may be sent to the Director of ISRA or to the corresponding author of this publication. Seed of Amina, Haby, and Dioufissa have been deposited to the USDA-ARS National Library for Genetic Resources, where seeds will be available 5 years after publication.

AUTHOR CONTRIBUTIONS

Amadou T. Sall: Conceptualization; data curation; formal analysis; investigation; methodology; validation; writing—original draft. **Filippo M. Bassi**: Conceptualization; investigation; methodology; resources; supervision; validation; visualization; writing—review and editing. **Hafssa Kabbaj**: Data curation; writing—review and editing. **Habibou Guèye**: Investigation; writing—review and editing. **Madiama Cisse**: Investigation; writing—review and editing. **Sidi Ould Ely Menoum**: Writing—review and editing. **Meryem Zaim**: Writing—review and editing. **Felix Sagne**: Data curation; investigation; validation. **Sapan Kumar**: Data curation; investigation; validation. **Rodomiro Ortiz**: Conceptualization; funding acquisition; project administration; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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