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Innovation Platform: Approaches and Success Stories for Development and Out-Scaling of Heat Tolerant Wheat Varieties in Africa

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Abstract

African agriculture faces critical challenges of ensuring food security for a fast- growing population; providing livelihoods for the farming community contributing toward SDGs goals; maintaining the sustainability of the sector in the face of rapid climate change. Wheat, cultivated on a total area of 10 million hectares annually with a total production of 28 million tones, is one of the most important food security crops in Africa. There is a huge gap between wheat production and supply in Africa due to low production level, increasing demand associated with the surge in urban population, and change in food preferences. To offset this gap, Africa imported about 55 million t in 2020/21 of which 27 and 28 million t destined to SSA and North Africa, respectively. Wheat production in Africa could be increased through the development and deployment of improved technologies (improved varieties, quality certified seeds, irrigation, agronomic practices, fertilizer and pesticides), and better institutional and market arrangements creating incentives for broader wheat sector actors involved in wheat production, marketing and processing. During the last 10 years, ICARDA in partnership with the national agricultural research systems in Africa, has implemented SARD-SC (Support Agricultural Research and Development-Strategic Crops) and TAAT (Transformation of African Agriculture Technology) through financial support from the African Development bank (AfDB). Both SARD-SC and TAAT adopted Innovation Platform (IP) approach for technology validation, promotion and scaling. IP is a multi-stakeholder alliance composed of groups of individuals with different backgrounds and expertise representing different research for development organizations which is established or organized at two levels: Strategic and operational levels. It is composed of (farmers, input producers and suppliers, traders, millers, food processors, researchers, extensionists, government officials) who come together on a common space and time (platform) to identify and prioritize problems, conduct research and provide solutions, advocate for investments, mobilize resources, develop capacities, promote and scale technologies for greater impact. Key regional innovation platforms (IP) and satellite testing sites have been established in Ethiopia (EIAR, Kulumsa), Sudan (ARC, Wadmedani), and Nigeria (Lake Chad Research Institute) to serve as national and regional hubs for rainfed high lands, irrigated hot lowlands, and hot and humid lowlands of SSA, respectively. Using participatory variety selection (PVS) approach at the respective platforms, more than 40 wheat varieties of ICARDA-origin have been released by the national programs in Africa. Out-scaling of heat tolerant varieties with associated crop management packages has enabled to expand wheat production both vertically and horizontally, create jobs, and build national capacities. The irrigated wheat production in Ethiopia increased from 21,000 hectares in 2019 to more than 400,000 ha in 2022 in addition to the 1.8 million hectares cultivated under rainfed environments annually. Similarly, wheat production area has increased from 70,000 ha to 100,000 ha in Nigeria and from about 200,000 to 375,000 ha in 2020 in Sudan. Rapid technology development and deployment, accessibility and affordability of inputs, promotion of commercial farming and agro-processing industries, and establishment of conducive policies, marketing, information and infrastructures are key for transforming wheat production in Africa.

Keywords: Breeding; Challenges; Ethiopia; Production; Wheat

Abbreviations: AFDB: African Development Bank; ARC: Agricultural Research Corporation; CGIAR: Consortium of International Agricultural Research Centers; CWANA: Central And West Asia and North Africa; EGS: Early Generation Seed; EIAR: Ethiopian Institute of Agricultural Research; GAP: Good Agricultural Practices; ICARDA: International Center for Agricultural Research in the Dry Areas; IP: Innovation Platform; NARS: National Agricultural Research System; NGO: Non-Governmental Organization; PVS: Participatory Variety Selection; QDS: Quality Declared Seed; Sard-SC: Support Agricultural Research And Development-Strategic Crops; SDG: Sustainable Development Goals; SSA: Sub-Saharan Africa; TAAT: Transformation of African Agriculture Technology; VVT: Variety Verification Trial; YET: Elite Yield Trial

Introduction

Africa produces a total of 28 million t of wheat on approximately 10 million hectares [1] with varying levels of productivity. National average yields range from >6 t ha^{-1} in Egypt and Zambia under irrigation to < 2 t ha^{-1} in most rainfed wheat growing countries which is well below the global average of 3.3 t ha^{-1}. This low productivity is due to biotic and abiotic stresses, climate change, poor availability and increasing price of inputs, poor infrastructure and marketing and limited policy support for investments. The African continent is the world's biggest wheat importer with about 55 million t in 2020/21of which 27 and 28 million t landed in SSA and North Africa, respectively. Wheat is not a traditional crop in most sub-Saharan Africa countries, and its proper cultivation is little known to most farmers, unlike other local crops such as maize, sorghum, millet, rice, cassava and others. Wheat production in Africa could be increased through the development and use of improved technologies (improved varieties/seeds, irrigation, fertilizers, pesticides and good agricultural practices), and better institutional and market arrangements creating incentives for wheat producers and other actors involved in wheat marketing and processing [2-5] (Figure 1).

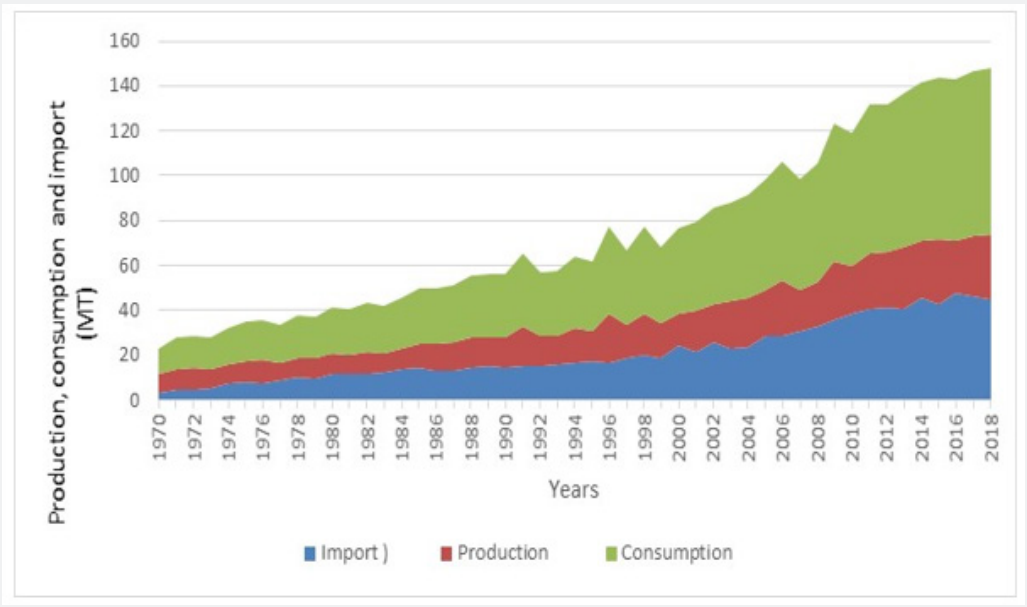

Figure 1: Production, consumption and import of wheat in Africa, 1970-2020.

To this end, agricultural research focusing on genetic improvement, agronomic management, mechanization, seed systems, marketing and infrastructure is critical to delivering a competitive wheat sector across the continent. Technology generation is a continuous process and for wheat there should be 1.6% genetic gain annually to cope with the increasing demand of wheat [3,6]. Research results from ICARDA and the national programs clearly show that wheat yield levels of 5-7 t ha^{-1} are easily attainable when high yielding, heat and drought tolerant wheat varieties with resistance to major diseases are grown using improved crop management technologies (improved varieties/seeds, irrigation, agronomic practices, fertilizer and pesticides). Therefore, it is important to develop a strategy/approach which enables continuous development and supply of wheat technologies with efficient and coordinated demonstration and out-scaling of technologies across the wheat value chain for greater impact [7].

Development of wheat varieties: breeding approaches and strategies

The wheat breeding program at ICARDA uses classical and molecular approaches to develop well adapted high yielding germplasm with resistance to the major biotic and abiotic stresses. The program has adopted a modified shuttle breeding program where the crosses and F1 production are carried out in the plastic houses followed by summer and winter shuttle of the F2, F3 and F4 head rows at [locations]. The stage 1 (preliminary yield) and stage 2 (advanced yield) trials are carried out during the main seasons at key locations: Merchouch and Settat (Morocco) for drought tolerance, Terbol (Lebanon) for cold tolerance and adaptation, Sids (Egypt) for yield potential, Wadmedani (Sudan) for heat tolerance and Kulumsa (Ethiopia) for resistance to diseases (yellow rust, stem rust, septoria etc). A total of 3000 and 600 wheat genotypes are tested in stage 1 and stage 2, respectively across the key locations [8]. This phase of the technology generation is totally managed by breeders/scientists from ICARDA and the national research centers (Figure 2).

Innovation platform (IP): Approaches and strategies

According to World Bank [9], innovation platforms are multi-stakeholder alliances composed of groups of individuals with different backgrounds and expertise representing their organization/institution (farmers, traders, millers, food

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processors, researchers, extentionists, government officials) who come together on a common space and time (platform) to identify problems, prioritization of policy, investment and research issues, discuss solutions, learn and research together, mobilize resources, develop capacities, promote and scale technologies for greater impact. Innovation platforms can be established at village, watershed, regional or national levels depending on their size and objectives [10]. Under both SARD-SC and TAAT projects, ICARDA and its NARS partners, adopted Innovation Platform (IP) approach as a strategy in improved wheat technology validation, demonstration, and popularization to create awareness and demand, and facilitate scaling for impact at scale. IPs established at strategic (policy) and operational (ground) levels provide an excellent forum to bring all wheat value chain actors together and define their roles and responsibilities. At operational level, each IP has a research, extension, and gender facilitator and women and youth are members of the IPs where they will be engaged in various activities of wheat value chain. At strategic level, it brings together intersectoral policy makers from research, development and financial institutions. IPs engage a broad range of multi-stakeholders: farmers, seed producers, inputs providers, extension services, research organizations, traders, financial institutions, agro-processors, sector associations, NGOs, and policy makers along the value chain (Figure 3). For the development of heat tolerant wheat varieties for Africa, ICARDA and national partners have selected three research.

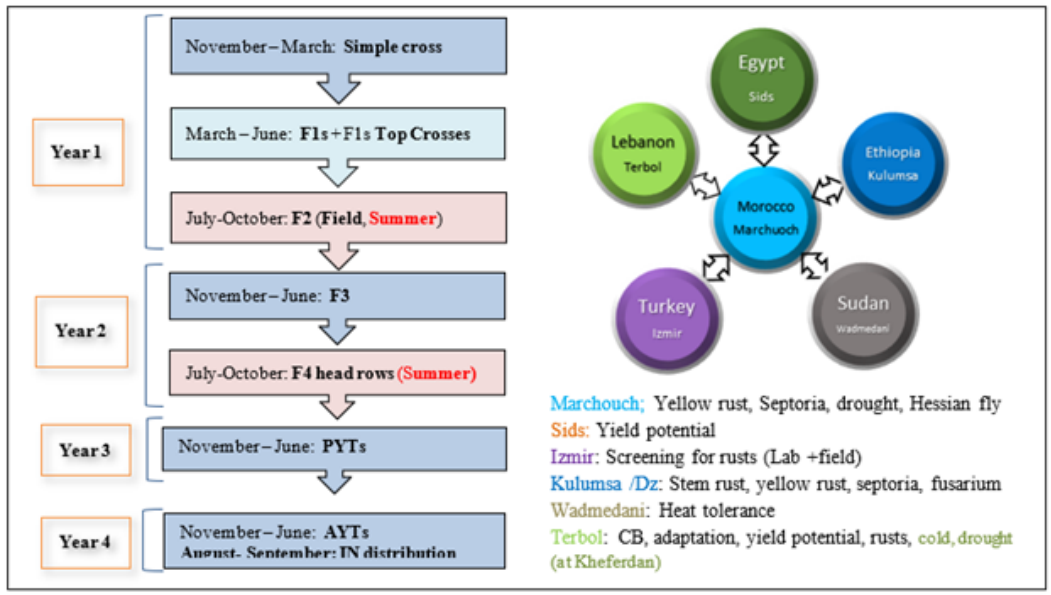

Figure 2: Wheat breeding schemes and key locations (research hubs) at ICARDA.

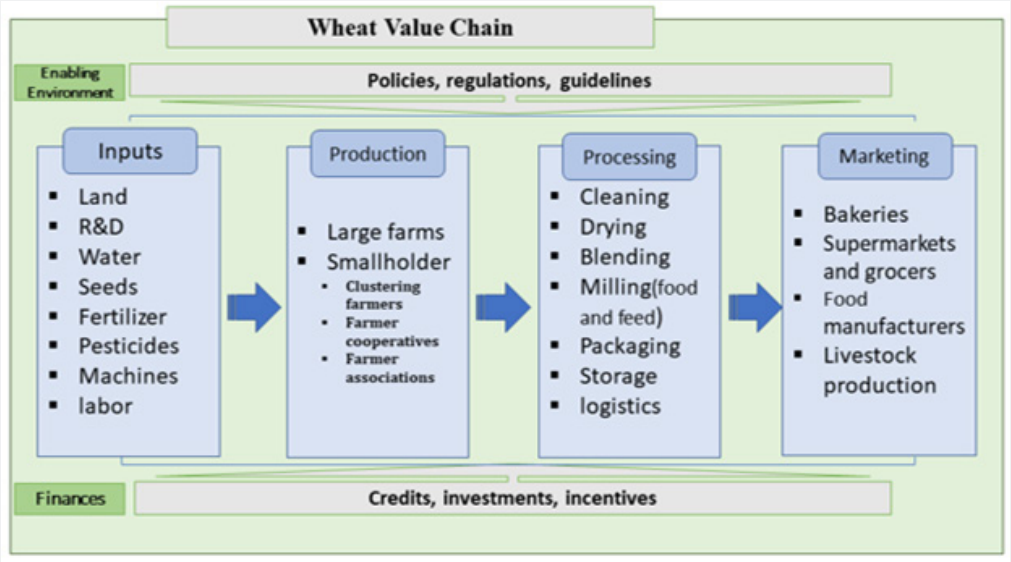

Figure 3: Global wheat value chain.

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hubs at national level: Lake Chad Research Center (Nigeria) representing West Africa, Merchouch (Morocco) representing North Africa, Wadmedani (Sudan) representing heat stressed environments and Kulumsa (Ethiopia) representing the rainfed highlands of East Africa. Satellite sites were established in the other project member countries to validate the results and ensure release of the new varieties within the national variety release and registration scheme. National programs carry out national or regional variety trials for 2-3 years followed by a 1-year variety verification/registration trials of 2-3 candidate varieties along with their national and local check varieties (Figure 3) Using such process, in the last 10 years alone, more than 65 bread wheat varieties of ICARDA origin have been released by National Agricultural Research System (NARS) in the CWANA and SSA regions (Figure 4).

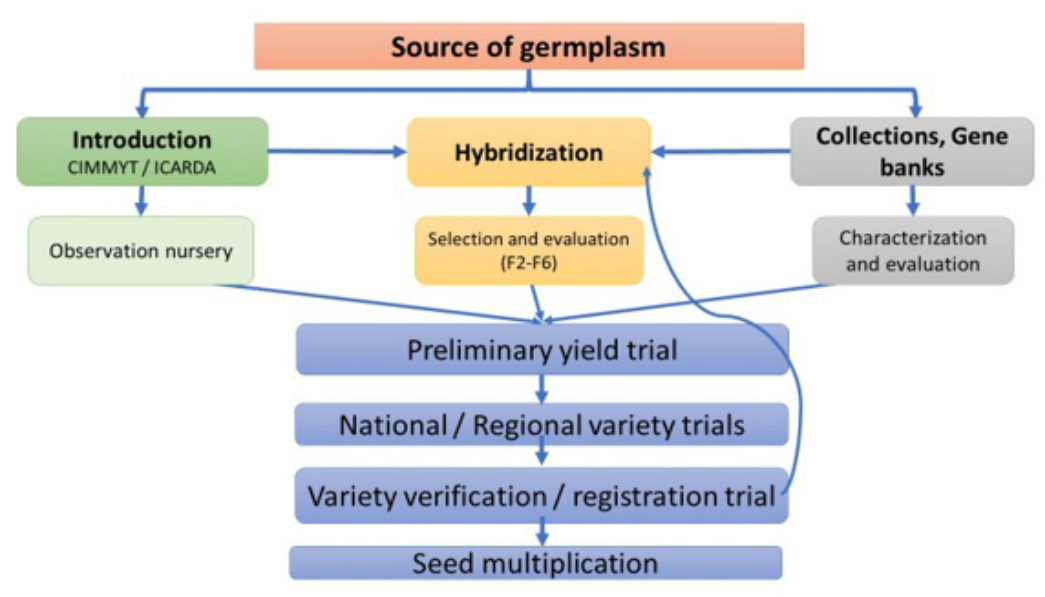

Figure 4: Variety development, evaluation, and release scheme in the national programs (Tadesse et al 2022).

What are the key functions and activities carried out at the hubs and IPs?

Priority setting and planning: Prioritization of challenges and innovation options based on preferences or expectations of informed stakeholders, for targeted resource allocation. Challenges and options can include access to information, technologies, finance or institutional gaps.

Clustering of farms: After thorough discussion and understanding, farmers agree to cluster their farms and apply the same wheat technologies and good agricultural practices. Such an approach is easy to introduce mechanization renting and utilizing machineries for ploughing, planting, pesticide application, harvesting and bundling of straws. Farmers will pay rent for machineries for each of the operations on hectare basis.

Good agricultural practices (GAP): Agro-ecology context toolkits of proven improved technologies were deployed to help achieve anticipated productivity and production targets. Wheat technology toolkit developed for outreach program where best bet crop management recommendations (improved variety, planting dates, seed rates, raised bed techniques/planters, fertilizer, irrigation, pesticides) are presented, discussed and implemented accordingly.

Participatory variety selection (PVS): The top 15-20 high yielding genotypes with resistance to biotic and abiotic stresses from stage 2 (advanced yield trials) of the wheat breeding program indicated above at ICARDA are assembled as Elite Yield Trial (EYT) and distributed in three sets for the project target countries (Ethiopia, Sudan, Nigeria, Kenya, Tanzania, Eritrea, Zimbabwe, Zambia, Lesotho, Mauritania, Niger and Mali). The EYT were tested at three locations in each of the member countries in general and at the hub countries (Ethiopia, Sudan and Nigeria) in particular with alpha lattice design in three replications using participatory variety selection (PVS) approaches where farmers, breeders and agronomists undertake selection of genotypes for yield, agronomic performance, adaptation and phenological traits. The selected 2-3 candidate varieties along with recent standard check will be further evaluated and released based on country variety release and registration scheme of the target countries. For example, in Ethiopia, the selected 2-3 candidate varieties along with recent standard check and/or local farmer variety are tested under variety verification trial (VVT) for one season both on-station and on-farm each in 100m2 (10m x 10m) non replicated plots. The national variety release committee, based on field evaluation and submitted data, decides to release, reject or repeat the variety. Up on release, 50-100 kg of breeder seed

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should be submitted to the national/regional seed enterprises for multiplication of pre-basic, basic and certified seed [11].

Accelerated seed multiplication of varieties: Candidate varieties, and/or released varieties were multiplied to produce enough quantities of early generation seed (breeder, pre-basic and basic) and certified seed. NARS produce early generation seed at the research sites and provide basic seed to private/public seed companies to produce certified seed complemented by quality declared seed by farmers groups at IP sites. The accelerated seed production particularly for EGS including pre-release seed multiplication, off-season seed production under irrigation has helped significantly to quickly out-scale the released varieties without any time lag.

Capacity building and strong support for farmers: Alongside new variety introduction, ICARDA carries out training, demonstrations, out-scaling and support for new, integrated approaches and improved crop management practices. Awareness creation and training on creation of business and entrepreneurship opportunities by deploying new technologies, markets, learning and networking are some of the capacity building activities carried out at the innovation platforms.

Partnership with stakeholders and resources mobilization: Assembling of diverse resources (financial, human, social and physical resources) by bringing all stakeholders together (farmers, farmer unions, seed producers, input suppliers, milling and food processing industries, development and extension departments, financial services, national governments, national and CGIAR research centers, etc.) together is very important to leverage change and bring impact along the wheat value chain.

Farm Mechanization and Service Contracting

The use of machineries such as tractors, planters, combine harvesters, seed cleaners etc facilitates agricultural operations and increases productivity. The innovation platform and clustering approach enables to organize service providers for ensuring machinery rental for farmers. The TAAT project has clearly demonstrated to national partners the importance of scaling mechanization and models for rentals and collective purchases in small scale and commercial enterprises.

Market-oriented value addition

For successful transformation of agriculture, it is important to orient it as business beyond subsistence farming for changing the livelihoods of farmers. Apart from local level value addition by women and youth group a more reorganized group approach should be envisaged in the endeavor. Farmers/cooperatives/unions should be organized in linking farmers to markets or value addition to wheat production. It is important that these organizations are involved in constructing storage facilities for aggregation and transportation, processing mills and small-scale food processing facilities (e.g. bakeries, etc) closer to production sites which does not require huge capital investments. There are compact milling machines for such decentralized operation available on the market. The TAAT project has helped national programs to augment market-oriented value addition along the wheat value chain.

Major Achievements and Impacts

Innovation platforms/research hubs have been successfully established

Key regional research hubs and satellite testing sites have been established in Ethiopia (EIAR, Kulumsa), Sudan (ARC, Wadmedani), and Nigeria (Lake Chad Research Center) to serve as national and regional hubs for rainfed highlands, irrigated hot lowlands, and hot and humid lowlands of SSA, respectively. These research hubs are owned by the respective national agricultural research systems to ensure continuity and sustainability beyond the life of the project cycle. Innovation platforms have been established in 12 SSA wheat growing countries where the TAAT project has been implemented. These platforms have played key roles in implementing the activities mentioned earlier through participatory approach and partnership of broad range of stakeholders which were very effective for participatory technology development, training, demonstration, out-scaling and advocate policy changes [12,13].

Heat tolerant varieties released and adopted

In the last ten years (2012-2022), more than 60 bread wheat varieties of ICARDA origin have been released by the national wheat breeding programs in CWANA and SSA regions. In SSA alone, more than 20 high yielding and heat tolerant wheat varieties of ICARDA origin have been released from 2013 to 2019 of which 15 were released across Ethiopia, Mali, Mauritania, Niger, Nigeria and Sudan. ICARDA wheat varieties are early maturing (90-100 days) with high biomass, high grain yield potential even under heat stressed environments, and good bread making quality (14-15% protein content) suitable for milling and food processing purposes (Table 1).

Increased rate of genetic gain: The deployment of the modified speed/shuttle breeding and key location testing along with the innovation platform and participatory variety selection (PVS) approaches and strategies in the ICARDA's wheat breeding program has resulted in the increase of genetic gains for yield and resistance to major abiotic and biotic stresses [14]. Genetic gains in Ethiopia has increased at the rate 0.30q/ha from 1970 to 2022 [2]. Similarly, yield levels of the current top yielding elite genotypes range up to 6 t· ha^{-1} at Wadmedani station of Sudan under extreme heat stress, 7 t·ha^{-1} at Merchouch station of Morocco under terminal moisture stress (260–300 mm) and 11 t· ha^{-1} at Sids station in Egypt under optimum conditions. Genetic gain analysis from 1980 to 2021 showed 2.5, 1.3 and 2.3% $year^{-1}$ increment at Merchouch, Wadmedani and Sids stations, respectively [15] (Figure 5). Genetic improvements have been also reported for resistance to major diseases such as UG99 resistance, yellow rust resistance and Hessian fly resistance among others. Progress in improving nutritional quality of wheat including the identification of Fe and Zn rich wheat varieties have been reported.

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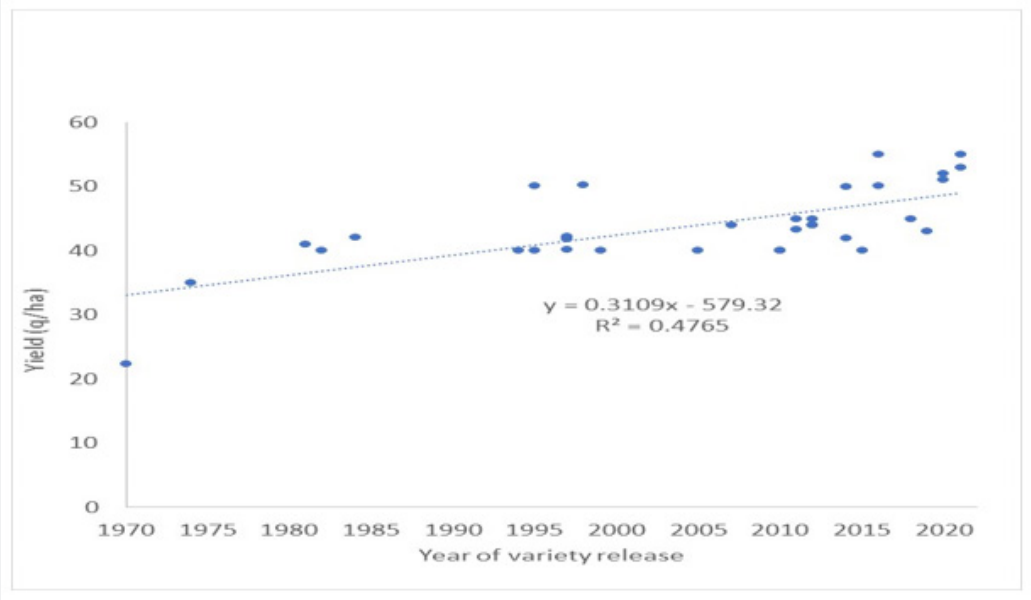

Figure 5: Yield (q/ha) of spring bread wheat varieties released in Ethiopia from 1970-2020.

Table 1: List and pedigree of ICARD-origin bread wheat varieties released in Africa from 2012-2022.

Country	Variety Name	Pedigree	Year of release	Average yield (t/ha)
Egypt	Sids 15	PARUS/PASTOR//FIDIYA-20/3/PASTOR//MILAN/KAUZ	2022	9.2
	Sids 16	OPATA/RAYON//KAUZ/3/ACHTAR/INRA 1764	2022	9.6
Eritrea	Sandal-4	CLEMENT/ALD'S'//ZARZOUR/5/AU//KAL/BB/3/BON/4/KVZ//CNO/PJ62	2015/16	4.5
	Quafza-3	SHA5//CARC/AUK/3/VEE#5//DOBUC'S'	2015/16	4.2
	Sidraa-1	GV/ALD'S'/5/ALD'S'/4/BB/G11//CNO67/7C/3/KVZ/TI/6/2*TOWPE	2015/16	3.5
	Jawahir-3	SHUHA-4//NS732/HER	2015/16	4
	GOUMRIA-3	VEE#7/KAUZ'S'	2015/16	4.3
Ethiopia	Obora	UTIQUE96/FLAG-1	2015	5.4
	Dambal	AGUILAL/3/PYN/BAU//MILAN	2015	5
	Fentale	FERROUG-2/FOW-2	2015	5.1
	Amibara	SHUHA-8/DUCULA	2015	4.8
	SHORIMA	UTQE96/3/PYN/BAU//Milan	2012	4.9
	HULUKA	UTQE96/3/PYN/BAU//Milan	2012	5.7
	Hachalu	RANA96/SIDS-1	2021	5.8
	Abay	BOUSHODA-1/4/CROC-1/AE.SQUARROSA (205)//KAUZ/3/SASIA	2021	6.25
Mali	Goumria-3	VEE#7/KAUZ'S'	2015	4.2
	Reyna 28	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	2015/16	4.5
Mauritania	Reyna 28	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	2015/16	4.3
Morocco	Snina	BT1735/ACHTAR//HUBARA-8	2018	4.5
	Melika	Achtar3*//'Kanz'/Ks85-8-4	2016	4.2
	Hfidt Nasma	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN/4/NES-MA*2/14-2//2*SAFI-3	2022	5.2

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Niger	Reyna 28	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S'	2015/16	4
	Goumria-3	VEE#7/KAUZ'S'	2015	4
Nigeria	LACRIWHIT-4	Attila/gan/Attila	2013	4
	LACRIWHIT-7	CROW'S'/BOW'S'-3-1994/95//TEVEE'S'/TADINIA	2015/16	4.5
	LACRIWHIT-8	REYNA-15 = CHAM4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S"	2015/16	7.7
	LACRIWHIT-9	PASTOR-2/KATILA-13//HAMAMS-5	2017	7.1
	LACRIWHIT-10	KAUZ'S'/SERI/3/TEVEE'S'//CROW/VEE'S'	2017	7
	LACRIWHIT-5	Norman	2014	5
	LACRIWHIT-6	Reyna-28	2014	5
Sudan	Khidaiwi	KAUZ//MON/CROW"S"/4/SERI.1B//KAUZ/HEVO/3/AMAD	2017/18	5.2
	Al-Shibaik	DEBEIRA/4/KAUZ//ALTAR 84/AOS/3/KAUZ	2017/18	5
	Amel	CROW'S'/BOW'S' -1994/95//ASFOOR-5	2017/18	5.1
	Salah	HUBARA-3*2/SHUHA-4	2017/18	4.3
	Jawahir	SHUHA-//NS732/HER	2017/18	4.5
	Goumria-3	VEE#7/KAUZ'S'	2013	4
Tanzania	Reyna 15	CHAM4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S"	2015	4.5
Zambia	LUMBE	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S''	2017/18	6.5
	TIMBA	NS732/HER/ARRIHANE/3/PGO/SERI//BAU	2017/18	6.7
	SISI	TEVEE'S'/KAUZ'S'//ASFOOR-1	2017/18	6.5
	KAKOBA	CHAM-4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S''	2017/18	6
Zimbabwe	Reyna 15	CHAM4/SHUHA'S'/6/2*SAKER/5/RBS/ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S"	2015	6.5

Wheat Area Expansion

The adoption and performance of wheat varieties by farmers in IP sites was tremendous where yields reached as high as 6 t ha-1 with significant increase in farmers' incomes. Area expansion registered in almost all countries (377,662 ha) with additional estimated production of (1.22 million t) at average productivity of 3.3 t ha^{-1}. In 2014/15, the wheat production area in Sudan was 224,700 ha and at a productivity level of 2.1 tons ha^{-1} producing 472,000 tons, a self-sufficiency ratio of 28%. By 2018/19, wheat was cultivated on a total area of 294,000 ha and at an average productivity level of 3.1 tons ha^{-1} producing about 900,000 tons of grain, a self-sufficiency of 45%. A bumper harvest and record production was achieved in the 2019/20 crop season and an area of 315,500 ha was harvested with productivity of 3.51 tons ha-1 and a total wheat production of 1.15 million tons achieving a wheat self-sufficiency of 50%. In 2020/21, about 375000 ha of wheat was planted and with expected productivity of 3.6 tons ha^{-1} and total production of 1.35 million tons. In 2019/20, average national wheat productivity reached 3.6 tons ha^{-1} whereas at Innovation Platforms it was 3.8 tons ha^{-1}. The increased area coverage, production and productivity were remarkable achievements resulting from strong partnerships, support, and dedication from all stakeholders not least of all the farming communities themselves.

In Ethiopia, about 21,000 ha of wheat was cultivated under irrigation along the three river basins on programs spearheaded by the Government of Ethiopia in 2018/19 season. At an estimated average yield of 4 t ha^{-1}, a total of 84,000 t of wheat was produced which helped the country to save about US$ 21 million. This is in addition to the 1.8 million hactares grown annually under rainfed conditions in the high lands of the country. In Nigeria, more than 26,000 t of certified seeds were distributed to more than 260,000 Nigerian wheat farmers. In Ethiopia, irrigated wheat production in 2022 reached more than 400,000 ha with expected production level of 2 million t. It is to be recalled that global wheat price has doubled in 2022 ($450 t^{-1} up from $250 t^{-1} a year ago) due to the Ukraine x Russia conflict. Many countries in the CWANA and SSA are struggling to get access to wheat market because of this crisis. The Ethiopian government has announced that it didn't import wheat in 2022 and planned to export wheat in 2023. This is a huge impact setting the beginning of the wheat green revolution in Ethiopia and in Africa [16].

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Accelerated seed multiplication

The wheat compact has successfully introduced diverse and accelerated seed production and delivery systems to accelerate technology dissemination and ensuring continuous access and deployment of high-quality seed in sufficient quantity to smallholder farmers. Accelerated early generation seed (EGS) multiplication by NARS coupled by large-scale certified seed production by partnering with public and private seed companies and quality-declared seed production by farmer groups and cooperatives at IP sites and beyond led to production of about 173,387 tons of seed (5,939 tons basic seed, 158,575 tons of certified seed and 8873 tons of QDS) of new and existing heat tolerant and/or rust resistant wheat varieties were produced, which readily deployed to about 1,733,437 beneficiary farmers. About 56, private and public seed companies as well as seed producer cooperatives and farmer associations were involved where their staff were trained and technically backstopped and engaged in wheat seed production.

For example, in Sudan, a wheat seed road map was developed to increase national seed supply. Prior to SARD-SC and TWC, wheat seed production seldom passes 5000 tons per year. TWC embarked in an ambitious plan of bulking of wheat seed to ensure the availability, access and use of quality seed which led to dissemination and adoption of heat tolerant improved wheat varieties. TWC in collaboration with ARC, supported early generation seed production by NARS and certified seed production in partnership with private seed companies and quality declared seed with farmer-based seed producers (communities, associations) at IP sites. In total, 93,034 tons of wheat seed produced comprising of 4, 184 early generation seed, 88500 tons certified seed and 620 tons quality declared seed. This can be estimated to cover about 930,034 ha. About 12 private seed companies and eight farmer-based community seed producers at eight IP sites were involved in wheat seed production. During the last few years, a significant increase in wheat seed production was observed commensurate with area expansion and in excess to national demand for potential export.

Job creation: Additional job creation for farmers, youth and women in wheat grain production, seed production, value addition and allied services (machine rentals, services) were possible in the project member countries. In the TAAT project, about 112,774 additional jobs were created of which 44% were youth and women. About 982 youth (28.5% women) were organized in 47 groups in 38 IPs and engaged in different businesses (machine rentals, small mills, bakery, seed processing etc).

Training: Farmers, youth, seed experts, development agents through FFS, hands-on practical trainings and farmer-to-farmer interactions were carried out and about 37,383 people were trained of which 34% are women and 12% are youth. A total 100 field days were organized and about 14090 participants attended by value chain actors from farmers to policy makers.

Scalability and the Way Forward

Wheat consumption in Africa has increased over years due to population increase, change in food habits and rapid urbanization, causing a huge gap between local wheat production and demand which in turn forces the continent to rely on import by incurring billions of dollars on annual basis. However, the option of importing wheat is not always easy and reliable as it depends on the availability of wheat in the global market, ability to compete and buy on time where there is a price-shock due to low production of wheat at global level as exemplified in 2008 and 2010 associated with climate change effects (occurrence of severe heat and drought stresses, aggressive diseases and pests) and currently in 2022 due to the Ukraine-Russia crisis and climate change. During such crisis, even countries which have the money to buy at any cost might have no access because of the export ban by the wheat producing countries.

Recent studies on the profitability and potential of wheat production in Africa indicated that 12 countries have huge potential to grow wheat profitability and economically. The three countries with huge expansion potential are Ethiopia, Sudan and Nigeria. The expansion of irrigated wheat production in Ethiopia from almost none in 2015 to 500,000 ha in 2022 is a magnanimous achievement. The government of Ethiopia has planned to expand irrigated wheat production up to 1 million hectares in the coming 5 years. Similarly, the governments of Sudan and Nigeria have planned to potentially expand wheat production from the current levels of 300,000 ha and 100,000 ha, respectively to 500,000 ha and 650,00 ha in the coming 5 years. Similar expansion plans have been set by the other potential wheat growing countries in Africa to lower the gap between wheat demand and supply. The future growth of wheat production in Africa is expected to come from use of climate smart/resilient varieties (tolerant to heat, drought, salinity; acidity, pre-harvest sprouting, nutrient and water use efficient); area expansion, lime application, integrated crop management (mechanization, fertigation, chemicals for pest control); and genetics (hybrid wheats, super wheats etc). The following recommendations are important for the successful implementation of wheat production in Africa.

Rapid Technology development and deployment

To date, the wheat breeding programs in Africa are totally dependent on the germplasm supply from the International Agricultural Research Centers (IARC). The IARCs (ICARDA and CIMMYT) are there to support national programs both in germplasm development and capacity development so that the national programs can be able to develop and deploy varieties specific to the different agro-ecologies of their countries rapidly and efficiently with accelerated genetic gain [4]. To this end, National programs in Africa should develop a strong national and regional breeding program. The current shuttle breeding scheme at Kulumsa ARC in Ethiopia enables to develop elite genotypes within a total breeding cycle of 4 years. This shuttle breeding

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program could be utilized for germplasm development and supply for the whole of Africa as the Kulumsa ARC was previously selected as Wheat Center of Excellence for SSA. Cognizant of this, it is important that the AfDB as a main proponent and pioneer of Feed Africa strategy where wheat is one of its commodity flagships together with the respective national MoA, NARES and other stakeholders to uphold this vision and promote the KARC as Africa's Wheat Research Center following the modalities of the Africa Rice.

Availability, access and affordability of inputs

Agricultural technologies (improved seeds, fertilizers, pesticides, irrigation facilities, farm machineries, communication tools, etc) have huge roles to increase agricultural productivity. It is not only the development of the technologies that matters but also their availability in time and space plus affordability in terms of price plays significant role in the adoption and scaling of agricultural technologies. To this end, establishment of robust seed system, fertilizer and chemical industries, machineries (tractors, planters, harvesters, etc) through private and public partnership along with efficient marketing systems, strong infrastructure, policy and legal frameworks are of paramount importance [17].

Promotion of commercial agriculture and agro-processing industries

Agriculture in Africa is dominantly carried out by smallholder subsistent farmers. Lack of capital, knowledge, conducive policies and infrastructures are some of the limiting factors for the establishment and promotion of commercial agriculture and agro-processing industries in Africa. Commercial wheat production is intertwined with modern storage facilities, milling, and food processing industries. They need to develop together across the wheat value chain. Understanding the national and global influences, it is important for agricultural professionals to learn from past experiences of their colleagues who pioneered private farms and the current private banking sector and form joint ventures in establishing commercial farming, seed companies, milling industries and bakeries by involving volunteer shareholders to mobilize resources. Such tangible efforts will enable to modernize the agricultural sector and increase productivity, create jobs, wealth, substitute imports, ensure food security and self-sufficiency to avoid dependency on food aid and imports.

Conclusion

The development and deployment of heat tolerant varieties in SSA especially in Ethiopia and Sudan through the support of the TAAT project has clearly demonstrated the importance of innovation platform approaches for rapid wheat technologies development, fast track seed multiplication and out-scaling for greater impact. The involvement of all stake holders including policy makers along the wheat value chain was one of the key factors which helped for greater adoption. The current achievement in Ethiopia sets the beginning of the wheat green revolution in Africa indicating that Africa indeed has a huge potential to grow wheat and feed itself if policy makers are committed to invest and put in place the right policies across the entire wheat value chain.

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