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# Wheat production and breeding in Sub-Saharan Africa

## Challenges and opportunities in the face of climate change

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**Abstract**

**Purpose** – This paper aims to review the current status of wheat production, farming systems, production constraints and wheat demand-supply chain analysis; the role of international and national breeding programs and their approaches in wheat genetic improvement including targeting mega environments, shuttle breeding, doubled haploids, marker-assisted selection and key location phenotyping; and future prospects and opportunities of wheat production in Sub Saharan Africa (SSA).

**Design/methodology/approach** – Relevant literature works have been used and cited accordingly.

**Findings** – Though traditionally wheat was not the leading staple crop in SSA, it is becoming an important food crop because of rapid population growth associated with increased urbanization and change in food preference for easy and fast food such as bread, biscuits, pasta, noodles and porridge. In 2013, total wheat consumption in SSA reached 25 million tons with import accounting for 17.5 million tons at a price of USD6 billion, while during the same period the region produces only 7.3 million tons on a total area of 2.9 million hectares. The low productivity (2t/ha) in the region is principally because of abiotic (drought and heat) and biotic (yellow rust, stem rust, septoria and fusarium) stresses which are increasing in intensity and frequency associated with climate change. Furthermore, increased cost of production, growing populations, increased rural-urban migration, low public and private investments, weak extension systems and policies, and low adoption rates of new technologies remain to be major challenges for wheat production in SSA. Wheat breeding in SSA is dominantly carried out by National Agricultural Research Systems, in partnership with the international research centers [International center for improvement of maize and wheat (CIMMYT) and International center for agricultural research in the dry areas (ICARDA)], to develop high yielding and widely adapted wheat genotypes with increased water-use efficiency, heat tolerance and resistance to major diseases and pests. Most of the cultivars grown in SSA are originated from the international research centers, CIMMYT and ICARDA.

**Practical implications** – This paper will help to promote available wheat technologies in SSA by creating awareness to wheat scientists, extension agents and policymakers.

**Originality/value** – This manuscript is an original review paper which has not been published in this form elsewhere.

**Keywords** Challenges, Wheat, SSA, Production, Breeding

**Paper type** General review



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## 1. Introduction

Wheat is the most important food security crop at the global level with a production of 750 million tons (MT) on about 220 million hectares (Mha) in 2017. Africa produces more than 25 million tons of wheat on 10 Mha. Sub-Sahara Africa (SSA) produced a total of 7.5 MT on a total area of 2.9 Mha accounting for 40 and 1.4 per cent of the wheat production in Africa and at global levels, respectively (FAO, 2017). Bread wheat, which accounts for 95 per cent of the wheat production at the global level, is also the dominant wheat type produced in SSA. Trend analysis of wheat production in SSA from 1970 to 2014 (Figure 1) indicates that the total wheat production area showed slight reduction, while the total production has increased from 2.8 to 7.5 MT because of the increase in productivity of wheat from 1.3 t/ha in 1970 to 2.1 t/ha in 2014.

The most important wheat producing countries in SSA are Ethiopia, South Africa, Sudan, Kenya, Tanzania, Nigeria, Zimbabwe and Zambia in descending order. Ethiopia accounts for the largest production area (1.7 Mha) followed by South Africa (0.5 Mha).

Though traditionally wheat was not the leading staple crop in SSA, it is becoming important through time, especially in the urban areas. The rapid population growth coupled with increased urbanization and change in food habits has resulted in the surge for wheat demand in SSA. On average, from 2011 to 2013, SSA countries imported 16.9 MT of wheat at a cost of USD6 billion which of course depletes the meager foreign currency reserve of the respective countries.

The increasing demand for wheat at global level, on the one hand, and the challenges facing wheat production such as climate change, increased cost of inputs, increased intensity of abiotic (drought, heat) and biotic (diseases and pests) stresses, on the other hand, make the wheat demand-supply chain very volatile and at times lead to social unrest. It is projected that demand for wheat in developing countries will increase by 60 per cent in the year 2050 (Rosegrant and Agcaoili, 2010). In 2025, wheat consumption in Africa is projected to reach 76.5 MMT of which 48.3 MMT would be imported accounting for 63.3 per cent of wheat demand at the current status quo. Almost all countries of North Africa (Algeria, Egypt, Libya, Morocco and Tunisia), Nigeria in West Africa, Ethiopia and Sudan in East Africa and South Africa accounted for 80 per cent of wheat imports. On the other hand, climate-change-induced temperature increases are estimated to reduce wheat production in developing countries by 20-30 per cent (Easterling *et al.*, 2007; Rosegrant and Agcaoili, 2010). Wheat production will also suffer the effects of stagnating or decreasing on-farm productivity, falling irrigation water supplies, declining soil fertility, monocropping, and

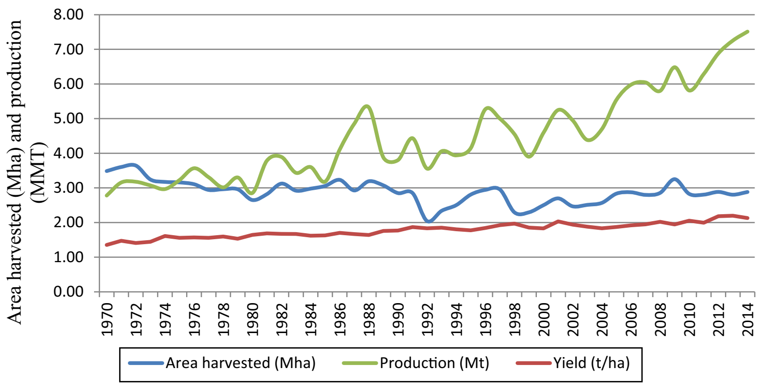


**Figure 1.**
Area, production and yield of wheat from 1970 to 2014 in SSA region

threats from emerging diseases such as the temperature tolerant and aggressive yellow rust races, and the recent epidemics of Ug99 stem rust in East Africa (Solh *et al.*, 2012). Furthermore, growing populations, increased rural-urban migration, low public and private investments, weak extension systems, inappropriate agricultural policies, and low adoption rates of new technologies remain to be major challenges for wheat production in SSA.

Recent studies about the potential and profitability of wheat production in SSA have indicated that some of the challenges indicated here can be opportunities (Negassa *et al.*, 2013). There is a huge potential to expand wheat production into the non-traditional wheat areas by applying improved crop management practices and installing favorable policy to enable the availability and accessibility of inputs, extension services, transportation and marketing infrastructures.

## 2. Status of wheat production in Sub-Saharan Africa

### *2.1 Major wheat growing environments*

Though there are a high degree of environmental variations in each country and across the region, based on moisture availability, cropping systems and temperature regimes, the wheat production area in SSA can be divided into two major mega-environments: rain-fed and irrigated. The rain-fed production system exists dominantly during the summer season in the highlands of Eastern Africa (Ethiopia, Eritrea, Kenya, Uganda, Rwanda, Burundi and Tanzania) and South Africa. The irrigated systems, on the other hand, are commonly practiced during the dry winter season in the lowlands of Southern Africa (Zambia, Zimbabwe, Malawi, Madagascar and Mozambique), Western Africa (Nigeria, Senegal and Mali) and in the low lands of Sudan. In South Africa, irrigated wheat is grown during the summer season.

Though we have divided the environment in SSA into two major mega environments, it is important to note that in each country and at regional level, there is a high degree of diversity and environmental variability. There is a huge potential for the expansion of irrigated wheat production in the region particularly in Sudan, Zimbabwe, Zambia, Nigeria, Somalia, and the lowlands of Ethiopia if irrigation facilities are to be installed.

Spring bread wheat cultivars are cultivated dominantly in the SSA region except in South Africa where the spring wheat is grown during the winter season under irrigation, while the winter/facultative wheat types are dominantly grown during the summer rainfall season accounting for about 20 per cent of production (Negassa *et al.*, 2013).

### *2.2 Challenges to wheat production*

*2.2.1 Abiotic and biotic stresses.* Wheat production in SSA is constrained by a number of abiotic and biotic stresses at different levels of intensity across rain-fed and irrigated environments. This is further accentuated by the increasing incidence of climate change, characterized by rising temperature (heat), less and erratic rainfall (drought) or sometimes excessive rainfall (flooding), and when combined with virulent pests and diseases, it makes agricultural productivity less predictable.

2.2.1.1 Abiotic stresses. In the rain-fed environments, the most important abiotic stresses are drought, soil acidity, erosion, poor soil fertility, water-logging and pre-harvest sprouting. Such constraints are most common in the East African highlands of Ethiopia, Eritrea, Kenya, Tanzania, Uganda, Rwanda and Burundi. Similarly, the rain-fed environments in the mid altitude areas of South Africa, Angola, Zambia, Malawi and Madagascar face these challenges. Heat and lack of water for irrigation are the most important abiotic constraints in the irrigated environments of Sudan, Nigeria, Zambia, Zimbabwe, Mali, Malawi, Senegal, Chad and Somali. Associated to climate change, high temperature during reproductive stages of wheat causes significant yield loss and grain quality reduction mainly because of reductions in the duration of developmental stages, lower biomass, early leaf senescence and adverse physiological and biochemical changes (Lobell *et al.*, 2011; Chand *et al.*, 2014). For every 1°C rise of temperature, the global wheat production is predicted to reduce by 6 per cent (Asseng *et al.*, 2015). In China, wheat yield reductions of up to 10 per cent is estimated for 1°C temperature increase during the growing season (You *et al.*, 2009).

2.2.1.2 Biotic stresses. The most important biotic constraints which affect wheat production in SSA include diseases, insects and weeds. Rusts (*Puccinia* spp.), Helminthosporium, septoria (*Septoria tritici*), tan spot (*Pyrenophora tritici repentis*), fusarium (*Fusarium spp.*), the bunts and smuts, take-all and root rots are important wheat diseases common in the region, especially in the East African highlands of Ethiopia, Kenya, Uganda, Tanzania, Rwanda and Burundi. With the current climate change effects, it is anticipated that new pests and diseases will emerge as already exemplified in the recent epidemics of stem rust strain Ug99 and yellow rust across the Central and West Asia and North Africa (CWANA) region and the Ug99 stem rust epidemic in East African countries (Solh *et al.*, 2012). Yellow (stripe) rust is caused by *Puccinia graminis f. sp. tritici* is the most prevalent and devastating disease in the East African highlands. It has caused significant yield losses ranging up to 100 per cent in the Ethiopian highlands as evidenced by the collapse of the dominant wheat varieties such as the semi-dwarf wheat variety Laketch in 1977; Dashen, a poplar high yielding variety with Yr9 gene from 1B/1R translocation in 1988 and in 1994; and Wabe in 1998 (Hulluka *et al.*, 1991; Badebo *et al.*, 2008). Galema (HAR 604) and Kubsa (HAR 1685) with Yr27 gene were dominant bread wheat varieties in the highlands and mid-altitude areas of Ethiopia, respectively, until they were wiped out by yellow rust in 2010 causing up to 100 per cent yield loss. Stem rust caused by *Puccinia graminis f. sp. tritici* is prevalent in the low and mid-altitude areas with warmer temperature. In Ethiopia, stem rust epidemics has knocked out major cultivars such as Enkoy with *Sr36* gene in 1994; and Digalu with $SrTmp^{+}$ gene in 2013 and 2014, causing 100 per cent yield loss (Badebo and Hundie, 2016). The Digalu race (TKTTF) which is different from the Ug99 race (TKTTSK) is dominant across the major wheat growing regions of Ethiopia (Badebo and Hundie, 2016) and becomes a major threat to wheat production in the country.

Of all the insects attacking wheat crop, wheat stem sawfly and Russian wheat aphids cause significant economic losses in SSA. Weeds dominantly grass weeds cause significant wheat production loss across many countries of the region (Tanner *et al.*, 1994; Tadesse *et al.*, 2016).

*2.2.2 Limited availability and high price of inputs.* Wheat productivity in SSA is dominated by subsistence farmers and its productivity is still very low partly because of the limited availability, accessibility and affordability of inputs such as fertilizers, improved seeds, irrigation water, pesticides and farm machineries. The cost of fertilizer is increasing through time, especially when energy prices are high for the fact that the costs of natural gas used to produce ammonia is increasing, and indirectly through higher transportation costs. Lack of access to credits, roads and transportations also limit the availability of fertilizers, seeds and agro-chemicals to farmers at the right time when they need it.

Water availability and installation cost for irrigation are limiting factors to expand wheat production in the irrigated environments such as Sudan, Zimbabwe, Nigeria, Gambia, Senegal, Mali, Malawi and Somalia. Even if available, the current furrow irrigation system utilized by most farmers is not economical in terms of water use efficiency to sustain wheat production and further expansion.

*2.2.3 Yield gap and stagnating yield.* Yield stagnation is a complex issue, which might be the result of a combination of factors, such as approaching a genetic ceiling in wheat improvement, declining soil fertility, biotic and abiotic stresses associated with climate change, unfavorable policies and marketing and other factors. Some authors have attributed yield stagnation to the genetic ceiling in India and Europe, while others have reported the presence of genetic gain in both spring wheat (Manes *et al.*, 2012; Sharma *et al.*, 2012) and facultative winter wheat (Tadesse *et al.*, 2013). However, it is evident that the potential of new cultivars has not been fully utilized in most of the developing countries because of poor agronomic management, partial application of packages of inputs, reduced incentives and unstable market prices. Fischer *et al.* (2014) have reported yield gap levels for wheat ranging from 26 to 69 per cent at global level. However, the gap remains high, especially in developing countries, because of a lack of knowledge and information reflecting on the performance of extension services and seeds/inputs delivery systems. In Ethiopia, progressive farmers under optimum conditions could harvest up to 7 t/ha, while the national average yield is about 2 t/ha, indicating the presence of up to 350 per cent yield gap. Similarly, in Sudan, the national average wheat yield (2 t/ha) is very low compared to the average yield of 5-6 t/ha in the demonstration sites, indicating the presence of huge yield gaps. The situation is very similar across all the SSA countries, indicating the potential to increase wheat production in the region by lowering yield gaps.

### *2.3 Wheat cultivation and farming systems*

*2.3.1 Cultivation systems.* In SSA, both traditional and modern cultivation systems are practiced commonly. In the traditional system of wheat cultivation, farmers are totally dependent on their traditional know-how, and on the tools and resources available at their disposal. Conventional tools such as oxen and hoe are used to till the land, select and plant seeds, protect plants from competing fauna and flora and gather the harvest. Harvesting is done using sickles or sharp knives and threshed using animals or sticks followed by winnowing. The harvested grain is stored for local consumption and the straw is used for animal feed. Surpluses are marketed through nearby outlets. The productivity of such systems is usually low and depends primarily on the natural fertility of the soil and the availability of rainfall.

Unlike the traditional system, the modern cultivation system relies on the development, accessibility and utilization of innovation such as tractors, combine harvesters, inputs (water, improved seed, fertilizer and pesticides), knowledge, technology, management, investment, markets and supportive government policies. Wheat production in South Africa, Zambia, Mali, Kenya, Tanzania, Nigeria, and Sudan is mostly mechanized and farmers use tractors for plowing and planting and combine for harvesting. However, there are small-scale farmers in these countries still using the traditional system of wheat cultivation. In Ethiopia and Eritrea, wheat production is carried out under rain-fed conditions and farmers use both mechanized and draught animals for plowing and human labor for harvesting. In Angola, Burundi, Malawi and Uganda wheat production is rain-fed and farmers use hoe for land preparation/tilling.

*2.3.2 Farming systems.* In the rain-fed environments, different rotations such as legume-wheat, potato-wheat, or oil crops-wheat rotation systems are practiced. Legumes are playing an increasingly important role in rain-fed wheat production environments, especially in soils with low Nitrogen (N) content by enriching soil N through biological N fixation, enhancing water use efficiency and breaking the cycle of weeds, pests and diseases, which affect wheat production. Grain legume species and varieties growing in the same location differ significantly in dry matter production, N accumulation, $N_2$-fixation, N-balance and residue quality (Evans *et al.*, 2001). These differences may be the main factors determining the residual N contribution to subsequent crops. Among the legumes, faba bean is the best N fixer with a mean of 100 kg N/ha, followed by groundnut and soybean (Smil, 1999).

Many experiments have shown that the introduction of legumes such as faba beans, chickpea and field bean in wheat-based cropping is a viable strategy for reducing the application of inorganic fertilizer and thus reducing the costs for resource poor small- and medium-scale farmers. In the highlands of Ethiopia, food legume crops are often grown in rotation with cereals or as intercrops to minimize the risks of drought and to manage soil fertility (Higgs *et al.*, 1990; Hailu *et al.*, 1989; Amanuel *et al.*, 2000). In a two-year cropping system, wheat after faba bean significantly out yielded wheat-wheat and wheat-barley rotation. According to Asefa Taa *et al.* (1997), faba bean-wheat rotation system has resulted in the increase of wheat yield by up to 77 per cent, and in the reduction of fertilizer N application for wheat production. Similarly, introducing forage legumes into existing cropping systems at medium altitudes of Ethiopia has provided the opportunity to substitute fallowing of fields and fallow grazing as livestock feed source. Forage legumes such as *Vicia* and *Medicago* species have shown high potential for sequential cropping with wheat. A study indicated that wheat yield could be improved by 55-128 per cent by incorporating vetch or vetch/oat mixtures in the rotation (Keftasa, 1996). This is comparable or slightly higher than the rotation with faba beans, the common rotation crop in the region. Rotation of oil crops, such as canola, rapeseed, sesame and sunflower is important, as it enables to clean out some grassy weeds that are difficult to control in a continuous wheat production system, to loosen and soften the soil, because of the deep taproots of the oil crops, break disease and insect pest cycles and reduce the risk to farmers through crop diversification.

In the irrigated environments, wheat-rice, wheat-legumes or wheat-cotton rotation systems are practiced by growing wheat in the winter season. In the wheat-cotton rotation system, harvesting of cotton is delayed up to December which pushes the wheat planting date to the last week of December/beginning of January. Such delayed planting of wheat exposes wheat to heat stress in April during grain filling period causing not only reduction in wheat yield but also reduction in wheat grain quality. Identification and deployment of early maturing cotton and wheat varieties could help to adapt this system.

### *2.4 Current wheat area and production in Sub Saharan Africa*

According to FAOSTAT (2017), SSA accounts for 30 per cent of the total wheat area and production in Africa. The area (Mha), production (MMT) and yield (t/ha) of wheat for the countries in SSA from 1970 to 2014 is indicated in Table II. In SSA, Ethiopia is the largest wheat producer with the average annual production of 3.6 MMT on an average area of around 1.6 Mha during 2010-2014 mainly in Arsi, Bale, Shoa, Gojam, Gondar, Wollo and Tigray regions of the country. Both the area of wheat production and productivity has doubled during the past decade in Ethiopia as compared to the period from 1970 to 1990.

South Africa is the second largest producer with an average annual wheat production of 1.9 MT on average area of 524,000 ha during 2010-2014 with an average productivity level of 2-4 t/ha under rain-fed and 7-9 t/ha under irrigated conditions. The important wheat-growing regions in South Africa include the South Western parts of the Western Cape (Swartland and Rûens), Northern Cape, Free State, North West, Mpumalanga, Limpopo, KwaZulu-Natal, Gauteng and Eastern Cape.

In Kenya, during 2001-2014, about 372,000 tons of wheat has been produced annually on an average production area of 148,000 ha. The important wheat growing areas in Kenya includes Nakuru, Trans Mara, Uasin Gishu, Nyandarua, Narok, Meru Central, Trans Nzoia, Keiyo and Laikipia. During 2010-2014, Sudan, Zambia, Tanzania and Nigeria have grown wheat on 0.182, 0.036, 0.107 and 0.107 Mha at an average productivity level of 1.9, 6.7, 1.2 and 1.1 t/ha, respectively.

The total annual wheat production in other countries such as Rwanda, Zimbabwe, Eritrea, Uganda, Mozambique, Lesotho, DR Congo, Burundi and Angola for the period 2010-2014 is very small, ranging from 76,000 tons in Rwanda to 3,000 tons in Angola. During the periods 1970-1990, the highest average wheat yield (4.8 t/ha) was reported in Zimbabwe. However, during the periods from 2010 to 2014, the highest yield (6.7 t/ha) has been reported from Zambia followed by South Africa (3.6 t/ha), Kenya (2.5 t/ha), Zimbabwe (2.4 t/ha) and Ethiopia (2.2 t/ha) (FAO, 2017).

Eastern Africa and Southern Africa are the two most important wheat-growing regions in SSA. Trend analysis of wheat area and production in these regions from 1970 to 2014 indicated that wheat area and total production has shown an increasing trend in Eastern Africa, while it showed a decreasing trend in Southern Africa, especially after 1998 (Figure 2).

In both Eastern and Southern African regions, the yield of wheat has shown an increasing trend from 1970 through 2014. In Southern Africa, the average regional yield reached 2 t/ha in 1996, while in Eastern Africa, the average yield level of 2 t/ha was achieved later in 2010. Big improvements in wheat productivity has been achieved in the past five years reaching average yield level of 2.5 and 3.6t/ha in Eastern and Southern Africa regions, respectively, in 2014. Considering the potential yields reported in the irrigated environments of Southern Africa and the optimum rainfall areas of Eastern Africa, there is still a huge potential to improve wheat production in these two regions if farmers deploy improved varieties with recommended integrated crop management practices (Figure 3).

The trend of average wheat area, production and yield during the periods 1970-1990, 1991-2010 and 2011-2014 by countries in SSA is indicated in Table I. It is evident that wheat production in the past four decades has increased because of the increase in yield across most countries and through both increase in yield and production area in some countries, especially in Eastern Africa. Wheat area has increased tremendously in Ethiopia, Kenya, Nigeria, Tanzania and Rwanda. There is a huge potential to increase wheat production area under irrigation in Sudan, Nigeria, in the lowlands of Ethiopia, Somalia, Kenya, Senegal and

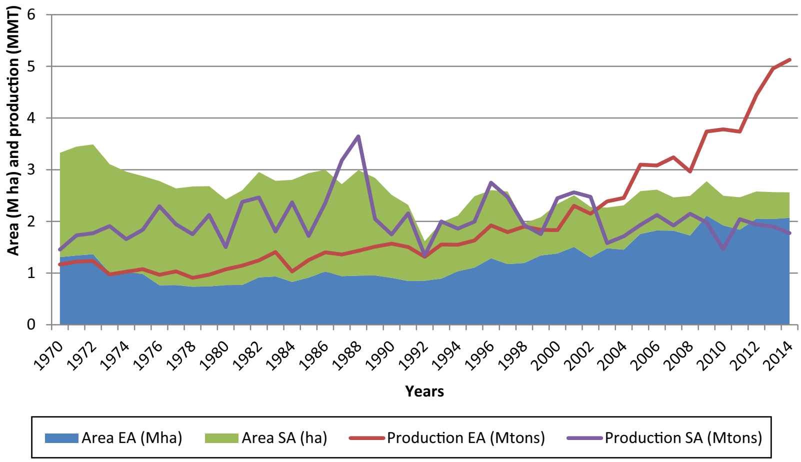


**Figure 2.**
Area (Mha) and production (MMT) in Eastern and Southern Africa regions, 1970-2014


**Figure 3.**
Trends of wheat yield (t/ha) in Eastern and Southern Africa regions, 1970-2014

**Table I.**
Wheat area harvested (Mha), yield (t/ha) and production (MMT) in SSA countries for the periods 1970-1990, 1991-2010 and 2011-2014

| Country | Area harvested (Mha) 1970-1990 | 1991-2010 | 2011-2014 | Yield (t/ha) 1970-1990 | 1991-2010 | 2011-2014 | Production (MMT) 1970-1990 | 1991-2010 | 2011-2014 |
|---|---|---|---|---|---|---|---|---|---|
| Ethiopia | 0.709 | 1.075 | 1.584 | 1.008 | 1.425 | 2.282 | 0.696 | 1.663 | 3.627 |
| South Africa | 1.885 | 0.920 | 0.524 | 1.085 | 2.278 | 3.609 | 2.043 | 2.003 | 1.885 |
| Kenya | 0.123 | 0.143 | 0.148 | 1.698 | 2.118 | 2.502 | 0.208 | 0.302 | 0.372 |
| Sudan | 0.170 | 0.253 | 0.182 | 1.245 | 2.053 | 1.851 | 0.204 | 0.494 | 0.339 |
| Zambia | 0.003 | 0.015 | 0.036 | 3.278 | 6.001 | 6.705 | 0.014 | 0.091 | 0.241 |
| Tanzania | 0.053 | 0.057 | 0.107 | 1.503 | 1.526 | 1.165 | 0.077 | 0.076 | 0.123 |
| Nigeria | 0.024 | 0.043 | 0.092 | 1.817 | 1.613 | 1.100 | 0.041 | 0.063 | 0.104 |
| Rwanda | 0.004 | 0.018 | 0.037 | 0.888 | 1.007 | 2.054 | 0.004 | 0.020 | 0.076 |
| Zimbabwe | 0.034 | 0.039 | 0.019 | 4.794 | 4.522 | 2.400 | 0.168 | 0.182 | 0.044 |
| Eritrea | – | 0.025 | 0.024 | 0.000 | 0.657 | 1.022 | – | 0.017 | 0.025 |
| Uganda | 0.005 | 0.008 | 0.014 | 2.061 | 1.750 | 1.549 | 0.010 | 0.013 | 0.021 |
| Mozambique | 0.005 | 0.004 | 0.017 | 1.093 | 1.164 | 1.221 | 0.006 | 0.005 | 0.020 |
| Lesotho | 0.048 | 0.022 | 0.014 | 0.740 | 0.811 | 1.001 | 0.033 | 0.017 | 0.014 |
| DR Congo | 0.006 | 0.007 | 0.006 | 0.678 | 1.262 | 1.304 | 0.004 | 0.009 | 0.008 |
| Burundi | 0.009 | 0.011 | 0.010 | 0.707 | 0.786 | 0.614 | 0.006 | 0.008 | 0.007 |
| Angola | 0.009 | 0.003 | 0.004 | 0.796 | 1.237 | 0.988 | 0.008 | 0.004 | 0.003 |
| *SSA* | *3.101* | *2.652* | *2.845* | *1.598* | *1.900* | *2.125* | *3.538* | *4.921* | *6.986* |
| *Africa* | *8.56* | *9.06* | *10.04* | *1.18* | *2.01* | *2.59* | *10.03* | *18.39* | *25.98* |
| *World* | *226.43* | *218.38* | *219.51* | *1.95* | *2.73* | *3.20* | *442.20* | *596.18* | *702.55* |

other SSA countries. For this to happen, however, favorable policies and strong commitments are required from the respective governments to build infrastructures, attract investments and create access to markets. Current intervention on promotion of wheat technologies in SSA through an ICARDA-led project supported by the African Development

Bank (AfDB) has shown that it is possible to increase wheat production and productivity by utilizing improved varieties, recommended agronomic packages and involving all stakeholders along the wheat value chain. Through the intervention of this project, 5-7 t/ha wheat yields were reported in Sudan, Nigeria and Ethiopia. Following demonstration of such results across many farmers' fields, there is a strong commitment from the governments of Sudan, Nigeria, Ethiopia and Kenya to expand wheat production area under irrigation to achieve self-sufficiency and curtail wheat imports (ICARDA, 2016).

## 3. Wheat consumption and end-uses in Sub-Saharan Africa

Wheat provides about 19 per cent of the calories and 21 per cent of protein needs of daily human requirements at the global level (Braun *et al.*, 2010). The flour of bread wheat is used to make French bread, Arabic bread, chapati, biscuits and pastry products and for the production of commercial starch and gluten. In Ethiopia, owing to the long tradition of wheat consumption, it has been used solely for French bread or in mixture with other cereals (barley, maize, sorghum, rice and millet) for the preparation of other dishes such as flat bread (*injera*), porridge, boiled grain (*nifro*), roasted grain (*kolo*), soup and preparation of local beer (*tela*).

Trends in wheat consumption increases globally and in SSA owing to population increase, rising household incomes, increasing opportunity cost of labor and expansion of urbanization. The average wheat consumption in SSA is 30 kg/capita/year, which is low as compared to North Africa, which has the highest wheat consumption rate (200 kg/capita/year). According to Shiferaw *et al.* (2013), the demand for wheat is growing fast in new wheat growing regions of the world such as Eastern and Southern Africa (5.8 per cent), West and Central Africa (4.7 per cent) and South Asia and Pacific (4.3 per cent). Trend analysis of wheat production and consumption in SSA from 1970 to 2014 (Figure 4) shows clearly that there is a huge gap between consumption and production.

Nigeria, Ethiopia and Sudan are the largest wheat importers in SSA (Table II). During 2011-2013, Nigeria imported on average 4.2 MMT of wheat annually at a cost of USD1.5 billion/year. In the same periods, Ethiopia and Sudan imported 1.6 and 1.5 MMT annually paying an average of USD600 and USD570 million/year, respectively. The trend shows that most of the countries except Angola, Central African Republic, Gambia and Gabon imported substantial amount of wheat annually because of the increase in demand.

The availability of wheat in the global market, the increasing population and urbanization, change of life style and the suitability of wheat for preparing fast foods could account for the surge in the demand of wheat in SSA. It is noteworthy to mention that the availability of wheat in the country might not replace wheat imports unless the local

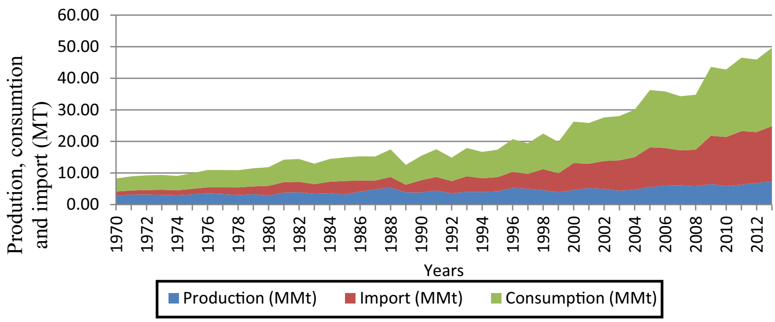


**Figure 4.**
Wheat production, consumption and import (MMT) in SSA region

| Country | Average 1970-1990 Import (Tons) | Average 1970-1990 Price (1000USD) | Average 1991-2010 Import (Tons) | Average 1991-2010 Price (1000USD) | Average 2011-2013 Import (Tons) | Average 2011-2013 Price (1000USD) |
|---|---|---|---|---|---|---|
| Nigeria | 6,39,662 | 1,45,401.7 | 20,07,581.2 | 3,85,909.9 | 41,55,229 | 15,09,610 |
| Ethiopia | 2,43,402.3 | 41,321.5 | 7,99,698.7 | 1,88,849.3 | 16,37,234.3 | 5,98,081.3 |
| Sudan | 2,41,169.7 | 38,845.8 | 8,29,963 | 1,79,980.9 | 15,35,023 | 5,66,226.3 |
| South Africa | 1,08,351.6 | 15,083.2 | 8,84,778.6 | 1,51,699.2 | 16,49,996.3 | 4,99,949.3 |
| Tanzania | 30,711.5 | 5,389.8 | 3,59,763.5 | 83,804.7 | 9,93,654.3 | 3,77,169 |
| Kenya | 88,744.2 | 14,138.5 | 5,04,804.8 | 1,00,807.1 | 11,83,103 | 3,37,104 |
| Côte d’Ivoire | 1,57,597 | 27,340.6 | 275,462 | 62,069.6 | 5,16,580.3 | 2,04,666.7 |
| Djibouti | 124.8 | 19.3 | 83,400.9 | 15,916.5 | 6,05,483.7 | 1,88,146.3 |
| Senegal | 1,24,742.6 | 21,201.2 | 2,66,527.6 | 63,985.6 | 4,82,597.7 | 1,83,714 |
| Cameroon | 47,473.6 | 8,960.5 | 2,08,946.1 | 55,233.4 | 4,73,498.7 | 1,83,186.3 |
| Uganda | 12,720.4 | 1,895.5 | 1,49,454.4 | 49,618.6 | 4,60,173 | 1,75,577.7 |
| Mozambique | 1,08,349.2 | 17,941.2 | 2,62,866.5 | 50,249 | 5,64,289 | 1,48,056 |
| DR Congo | 1,15,608.5 | 22,108 | 2,00,952.6 | 41,211.9 | 4,66,517 | 1,38,144.7 |
| Ghana | 1,01,355.4 | 16,814.3 | 2,35,816.9 | 65,838.8 | 2,58,798 | 1,17,263.3 |
| Mauritania | 40,358.7 | 5,992.4 | 1,86,159.4 | 37,129.4 | 3,97,124.3 | 1,15,956.3 |
| Zimbabwe | 43,053.5 | 6,166.4 | 103,413.6 | 33,872.4 | 2,24,310.7 | 1,09,259.7 |
| Malawi | 5,876.8 | 1,588.7 | 50,468.6 | 18,449.2 | 1,67,666.7 | 95,333.3 |
| Mali | 23,016.9 | 4,312.7 | 45,083.6 | 10,554 | 1,60,745.7 | 57,876 |
| Mauritius | 6,120.3 | 1,040 | 1,27,433.6 | 26,155.9 | 1,36,291.7 | 51,216.7 |
| Congo | 14,089.1 | 2,691.4 | 56,663.7 | 10,607.7 | 1,04,615.3 | 38,408 |
| Gabon | 65,903.6 | 4,735.2 | 94.9 | 13,643.5 | 0 | 36,536.7 |
| Togo | 28,245.9 | 6,230.8 | 74,003.1 | 17,137.8 | 76,433 | 32,080 |
| Burkina Faso | 19,957.3 | 4,162.1 | 42,460.3 | 11,237.6 | 67,485.7 | 30,130.3 |
| Namibia | 22,836.4 | 3,141.4 | 46,883.3 | 9,125.9 | 60,474 | 25,375.7 |
| Botswana | 9,771.1 | 1,601 | 47,423.4 | 12,516.2 | 62,033.7 | 22,330.3 |
| Rwanda | 3,801.1 | 1,406.3 | 6,680.1 | 2,559.7 | 58,533.7 | 22,299 |
| Eritrea | | | 1,53,207.7 | 24,329.7 | 72,316 | 20,926.7 |
| Lesotho | 18,414.3 | 3,514.2 | 57,405.8 | 7,737.1 | 78,230.7 | 18,150 |
| Burundi | 2,528.7 | 905.9 | 3,487.1 | 1,447.4 | 30,631 | 13,065.3 |
| Benin | 27,198.6 | 4,721 | 18,094.8 | 3,825.2 | 29,094.7 | 10,913.3 |
| Swaziland | 84.1 | 16.8 | 23,989.6 | 5,928.6 | 34,596 | 9,641.7 |
| Madagascar | 15,226.3 | 2,257.9 | 47,787.1 | 10,713.3 | 27,977.7 | 8,863 |
| Cabo Verde | 8,504.1 | 899.8 | 20,404.4 | 3,803.2 | 21,644 | 7,848 |
| Guinea | | | 52,667.6 | 10,270.3 | 21,052.3 | 7,361.7 |
| Liberia | 8,115.4 | 1,951.2 | 35,545.2 | 6,004.5 | 14,850.3 | 5,561 |
| Chad | 4,353.6 | 1,021 | 7,216.7 | 1,326 | 30,799.3 | 4,335.7 |
| Zambia | 89,123.8 | 12,644.2 | 44,305.2 | 12,185 | 5,387.7 | 3,164.3 |
| Gambia | 614.4 | 19.9 | | 3.2 | | 1,722 |
| Sierra Leone | 17,322.3 | 3,047.1 | 22,386.7 | 4,604.1 | 6,659 | 1,674 |
| Niger | 8,902.5 | 2,435.7 | 6,728.1 | 2,291.7 | 2,659 | 1,380 |
| Somalia | 23,837.7 | 4,382.2 | 32,574.2 | 6,637.5 | 3,169 | 883.7 |
| Seychelles | 216.2 | 38.3 | 220.5 | 116.4 | 190.7 | 91 |
| Angola | 72,633.3 | 11,153 | 26,793.9 | 4,209.5 | 14 | 12.7 |
| Central African Republic | 1,692.7 | 230.9 | 19.9 | 6.9 | 0 | 0 |
| Comoros | | | 0.6 | 1.1 | 0 | 0 |
| SSA Total | 2,601,812 | 4,68,768.6 | 8,409,620 | 18,03,605 | 1,68,77,163 | 59,79,291 |

**Table II.** Wheat import (Tons) and price (USD1000) in SSA countries, 1970-1990, 1991-2010 and 2011-2013 produce is of good quality for making bread and other products. In Ethiopia, for example, wheat produced in the high rainfall areas are mostly affected by pre-harvest sprouting and is not of good quality for making the common French bread. Accordingly, most of the millers in the country prefer the imported wheat to be used solely or in mixture with the local wheat. Similarly, wheat grown in heat stressed environments such as Sudan or Nigeria might not be as good as the imported wheat in terms of bread making quality.

We hope that as demand for specific products in SSA countries increases, there will be market segmentation for wheat products, based on visible or non-visible characteristics. This will create the potentials to expand the local industries to add value both in quality and quantity, create jobs and increase farm gate prices. As the principle of better price for better quality is established in the marketing system, farmers will be encouraged to grow wheat varieties with a reasonably high yield potential and good quality following improved management practices. In the past, the wheat improvement programs in most of the SSA countries have dominantly focused in the development of high yielding wheat varieties with resistance/tolerance to the major biotic and abiotic stresses with limited emphasis to end use qualities. To cope with the increasing demand for better quality wheat, it is important to develop wheat varieties with acceptable end-use quality and also improve the crop management practices. To this end, continuous investment in research, capacity building, better policy and awareness creation are highly important.

## 4. Wheat breeding in Sub-Saharan Africa

Wheat breeding at international and national level has played a significant role in the development of high yielding varieties with resistance/tolerance to the prevailing pests and diseases. The period of establishment, strength and success of the national wheat breeding programs in SSA varies across countries. However, most of them rely on the international centers (CIMMYT and ICARDA) for germplasm source, follow almost similar procedures of variety evaluation, and face similar challenges in terms of capacity development and seed systems.

### *4.1 The role of international wheat breeding in Sub Saharan Africa*

The CGIAR centers (CIMMYT and ICARDA) have been playing significant roles in germplasm development and distribution and capacity building (training) of the national programs. The wheat breeding program at CIMMYT and ICARDA applies both conventional and molecular breeding approaches and techniques to develop high yielding and widely adapted germplasm with resistance/tolerance to the major biotic and abiotic constraints prevailing in the developing world. Some of these strategies and techniques include classification of mega-environments (ME) and assembling of targeted crossing blocks, shuttle breeding, utilization of doubled haploids (DH) and marker-assisted selection (MAS), key location yield trials, distribution of germplasm to National Agricultural Research Systems (NARS) through international nurseries, and partnership and strengthening capacity of NARS (Rajaram *et al.*, 1995; Tadesse *et al.*, 2016). Almost all wheat varieties grown in SSA except South Africa are direct releases from CIMMYT/ICARDA germplasm distributed to the NARS through the international nursery system. Among the many crosses developed to date at CIMMYT/ICARDA, the VEERY cross (KVZ/BUHO//KAL/BB) and its derivatives have been by far the most successful cross enabling in the release of at least 65 varieties in more than 30 countries globally (Tadesse *et al.*, 2016). In SSA, the Veery cross has been released with different local names such as Dashen in Ethiopia; Loerie and Loerie II in Zambia; SCW101 in Zimbabwe; SASARAIB in Sudan; and TAUSI in Tanzania. Similarly, from the Attila cross (ND/VG9144//KAL/BB/3/YACO/4/

VEE#5), many mega cultivars have been released and grown across many countries. For example, Kubsa in Ethiopia and Imam in Sudan are the most dominant cultivars originated from Attila cross in SSA. Recently, from the CIMMYT/ICARDA wheat breeding programs, wheat varieties with UG99 stem rust resistance and heat tolerance have been released in SSA countries.

The wheat-breeding program at CIMMYT and ICARDA has established both short- and long-term training courses in wheat breeding to train young wheat breeders from the national programs. Many young breeders from the SSA countries have participated in the annual wheat breeding courses at CIMMYT and ICARDA. Furthermore, many MSc and PhD students from SSA have carried out their thesis research at CIMMYT and ICARDA in collaboration with national and international universities. These trainings enabled to promote the ideals of international wheat breeding, and development and release of many wheat varieties by the national programs.

*4.2 National wheat breeding programs*

In SSA, wheat breeding is dominantly carried out by agricultural research institutes and agricultural universities of the respective countries. Some of the strong research institutes and universities have reasonable number of research centers, sub-centers and testing sites addressing the major agro-ecologies of each country. However, even in these institutes and centers, the internal research facilities and manpower are very limited both in quality and quantity which is a major problem across all countries. Withstanding these challenges and constraints, the national breeding programs have been operating to develop high yielding wheat varieties with resistance/tolerance to the major biotic and abiotic constraints prevailing in the different agro-ecologies of each country.

The germplasm acquisition, development, evaluation and release follow the general procedure outlined in Figure 5 with slight modification at country levels. The national wheat research coordinating center of each country requests international wheat nurseries from CIMMYT and ICARDA, and grows the nurseries for further evaluation and selection either for direct release or parental purposes. Only few of the national programs in SSA such as Kulumsa (Ethiopia), Njoro (Kenya) and Wadmedani (Sudan) undertake their own crossing programs and subsequent evaluation of the segregating generations (F2-F6).

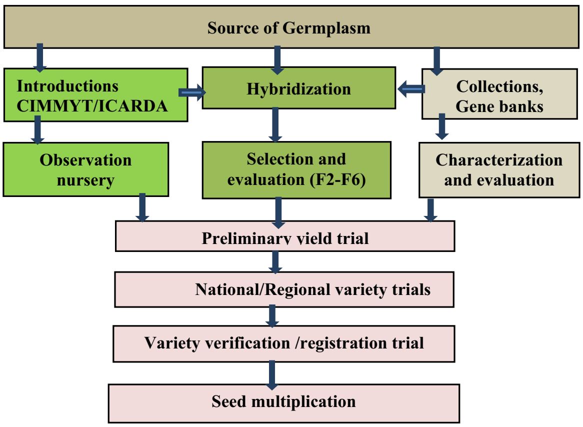


**Figure 5.**
Germplasm evaluation scheme in the national breeding programs

In South Africa, there are three main wheat-breeding programs, namely, Sensako (private 75 per cent market share), Pannar (private 10 per cent market share) and Small Grain Institute part of Agricultural Research Council (parastatal, 15 per cent market share). Sensako's wheat breeders have more than 200 combined years of experience in the group, most probably the most experienced wheat breeding team in Africa.

The pedigree-method of selection is the most common and practical, as the numbers of crosses are limited (50-300 crosses/year). Fixed germplasm obtained from the international centers or from the national programs is evaluated across locations in preliminary yield trial (PYT) for one year followed by national/regional variety trials (NVT/RVT) across locations for two years. Breeders need to apply for variety release and registration by submitting two years of the NVT/RVT data across locations along with the performance of candidates and check cultivars. After submission, the best two to three candidate varieties along with local and recent check varieties will be promoted into variety verification/registration trial (VVT) in which each variety is planted on 100 $m^2$ (10 x 10 m) non-replicated plots for one year both on station and on farm. Evaluation is made by the technical committee for variety release at grain filling stage for resistance to diseases, maturity, yield potential and farmers' preference. The technical committee reports its assessment to the national variety release committee which makes decision to release, reject or repeat the variety verification trial. Up on acceptance/release, 50-100 kg of breeder seed should be submitted to the national/regional seed enterprises for multiplication of pre-basic, basic and certified seed.

*4.3 Wheat varietal releases in Sub Saharan Africa*

Following this procedure, many varieties have been released by national programs. However, only few of the varieties were widely grown and adopted by farmers in each country (Table III).

*Ethiopia*: The Ethiopian Agricultural Research Institute has released more than 80 bread wheat varieties to date. However, only few of the varieties such as Laketch (PJ/GB55 or PENJAMO-62(SIB)/GABO-55) released in 1970, Enkoy (HEBRAND SAL/WIS24/SUP51/

**Table III.** List of major wheat research institutes and major cultivars in selected SSA countries

| Country | Institute/National coordination center | List of dominant historical cultivars |
|---|---|---|
| Ethiopia | EIAR, Kulumsa | Laketch, Enkoy, Dereselign, Pavon76, Dashen, Enkoy, ET-13A, Madda Walabu, Kubsa, Galema, Digalu |
| Kenya | KARI, Njoro | Kenya Kwale, Kenya Mbuni, Kenya Pasa |
| Sudan | ARC, Wadmedani | Debeira, Wadi el Neel, Nesser; Bohain; Baladi, Imam, Condor |
| South Africa | Sensako (Bethlehem); Pannar (Bloemfontein) and ARC-SGI (Bethlehem | ) | Inia, Betta, Belinda, PAN3191, Molen, PAN3120, PAN3364, SST25, SST66, SST44, SST 57, SST 75, SST 88, SST 94, T4, Gamtoos, SST825, SST876, SST806 |
| Tanzania | DRD | Mbuni, Trophy, Joli, Kozi, Tembo, Viri, Tausi, Selian 87, Kiware, Chiriku |
| Nigeria | Lake Chad Research Center | Debeira, SAMWHIT2, SAMWHIT 6 (veery), LALARCHWIT2, LARCHWIT3, LARCHWIT 4 |
| Zimbabwe | Crop Breeding Institute (CBI) | Scarlet, Smart, Shangawa, Sceptre, Scan, SC Nduna |
| Zambia | ZARI | Mexipak, Lorie and Lorie II, Sceptre, Scan, Smart, Dande |
| Burundi | ISABU | Romany, Cowbird, Hungenga |

(FR/FN/Y) and Dereselegn (CI8154/2*FR) released in 1974, ET13-A2 (Enkoy/UQ105) released in 1981, Pavon 76 (VICAM-71//CIANO-67/SIETE-CERROS-66/3/KALYANSONA/BLUEBIRD) released in 1982, Dashen (KVZ/BUHO//KAL/BB or AVKAZ/(SIB)BUHO//KALYANSONA/BLUEBIRD) released in 1984, Kubsa (ND/VG 9144//KAL/BB/3/YACO/4/VEE or NORD-DESPREZ/VG-9144//KALYANSONA/BLUEBIRD/3/YACO/4/VEERY) and Galema (4777*2//FKN/GB-AUS/3/PV or 4777*2//FKN/GABO/3/PAVON-76) released in 1995, MaddaWalabu (TL/3/FN/TH/NAR59*2/4/BOL'S') released in 2000, and Digalu (SHA7/KAUZ) released in 2005 have been grown widely. Some of the cultivars such as Pavon76, Kubsa and Digalu are grown widely with the application of fungicides to control rust diseases.

*Kenya*: The Kenyan Agricultural Research Institute has released many bread wheat varieties. Kenya Kwale (KVZ/TI/3/MAYA//BB/INIA) and Kenya Mbuni (ZA75/3/LD357E/TC//GLLA) released in 1987; Kenya Pasa (BUC/CHAT) released in 1989; Duma (AU/UP301//GLL/SX/3/PEW/4/MAI/MAYA//PEW released in 1993; and Njoro BW2 (TNMU) released in 2001 are some of the examples of cultivars adopted by farmers.

*Sudan*: Agricultural Research corporation released more than 25 bread wheat varieties in collaboration with international agricultural research centers (CIMMYT and ICARDA) and through bilateral country arrangements. However, as would be expected, only seven to eight of these achieved widespread commercial use. Imam (released in 2000) is the dominant variety and it occupies approximately 80 per cent of the area in the Gezira (Turner and Bishaw, 2017). DEBEIRA (HD2160/5/TOB/CNO67//BB/3/NAI60*2//TT/SN64/4/HD1954) in 1982; WADI EL NEEL (CHENAB70/GIZA155) in 1987; NESSER (W3918A/JUP) in 1997; and CONDOR (WW15*2/3/PJ/GB56//TZPP/NAI60) in 1978 have been cultivated.

*Tanzania*: Veery released in 1983 and again as Tausi (KVZ/BUHO//KAL/BB) released in 1987; and Mbayuwayu (KVZ/K4500 L.A.4) released in 1987 are some of the dominant cultivars.

*Nigeria*: SAMWHIT 2 (FLORENCE AURORE 8193) released in 1965; SAMWHIT 6 (VCM//CNO/7C/3/KAL/BB), SAMWHIT 7 (PITIC-62/FROND/3/PITIC-62/MAZOE//MEXIPAK) and SAMWHIT 8 (II54-388/AN/3/YT54/N10B//LR64) released in 1990; DEBEIRA (HD2160/5/TOB/CNO67//BB/3/NAI60*2//TT/SN64/4/HD1954) and LARCHWIT 1 (KVZ/BUHO//KAL/BB) released in 1997; LARCHWIT 2 (CIANO-79/PARULA//CHILER) and LARCHWIT 3 (LINFEN87.5071/ATTILA//ATTILA) released in 2005; and LARCHWIT 4 (ATTILA/GAN/ATTILA) released in 2008 have been cultivated in Nigeria.

*Zambia*: Mexipak (PJ/GB55) released in 1965; LOERIE II (KVZ/BUHO//KAL/BB) released in 1985 as Lorie and in 1987 as Lorie II; COUCAL (PF7339/HAHN) released in 1988; SCAN (VEE/BUC//PVN) and Sceptre (VEE/SENGWA) released in 1999 are some of the widely cultivated cultivars.

*Zimbabwe*: Rusape and W170/84 were released in 1983, 1989 and 1990, respectively, from the same pedigree (KVZ/BUHO//KAL/BB). This is the "Veery" cross from CIMMYT and more than 15 varieties have been released from this cross globally. Similarly, Sceptre in 1995, Scolar and Scope in 1996 were released from the same Pedigree (VEE"S"/SENGWA). Scan (VEE"S"//BUC"S"/PVN) released in 1994; Kana (FLY CATCHER/S78224//F84042(BJY/JUP)/F82022(F12.71/COC 75) released in 1999; and Smart (NATA/W31/89) and Dande (CAR422-ANA/SERI//L1555-6/VEE'S'-THB'S') released in 2001 were some of the varieties which have been grown widely in the country.

*South Africa*: Both facultative winter wheat and spring bread wheat cultivars have been widely grown in South Africa, more than a decade ago, currently spring wheat varieties are the dominant type of wheat produced in South Africa. Popular older winter and facultative varieties (Betta, Belinda, Molen, PAN3191, PAN3164, SST124, SST399, SST966 and

SST983) and older spring wheat varieties (T4, Gamtoos, SST88, SST57, SST66, SST825, SST876, SST806) were widely grown. Currently the most popular varieties are mostly spring wheat types, namely, SST056, SST087, SST0127, SST015, SST88, SST884, SST027, SST843, SST835, SST895, SST875, SST806, SST877, PAN3471, SST866 and PAN3408. Popular winter and facultative varieties are SST347, SST356, Matlabas, Elands and PAN3120. Unlike other SSA countries where most of the varieties were direct releases from CIMMYT, the wheat varieties in South Africa are derived from the crosses made within the country.

Recently, high yielding wheat varieties with resistance to Ug99 and heat tolerance have been released in SSA countries (Table IV). However, variety release alone will not bring the expected impact unless seeds are produced sufficiently, distributed and made available to farmers timely for which the availability of a functional and robust seed system is highly important. However, in most SSA countries, the seed system is relatively weak and still dominated by the public sector, both in terms of agricultural research (varietal releases) and seed delivery (quantity supplied). There are limited private seed companies like Seedco in SSA. In Eastern Africa, particularly in Ethiopia, the predominance of mega-varieties, the low varietal replacement rates and quick breakdown of rust resistance continue to be the main challenges of wheat sector.

There is a long time gap between wheat variety release and availability of certified seed in farmers' fields principally because of the limited capacity of the seed sector, the low multiplication factor and large quantities of seed required for planting and the poor infrastructure for marketing and transportation. The unstable policy frameworks and the

**Table IV.** List of some of the recently released wheat varieties with resistance/tolerance to Ug99 stem rust and heat stress in SSA

| Variety | Pedigree | Country | Year of release | Origin |
|---|---|---|---|---|
| Hidase | YANAC/3/PRL/SARA//TSI/VEE#5/4/ CROC-1/AE.SQUAROSA(224)//OPATTA | Ethiopia | 2012 | CIMMYT |
| Mandoyo | WORRAKATTA/PASTOR | Ethiopia | 2013 | CIMMYT |
| Shorima | UTIQUE-96/3/PAYNE/BAGULA//MILAN | Ethiopia | 2011 | ICARDA |
| Fentale | FERROUG-2/FOW-2 | Ethiopia | 2015 | ICARDA |
| Amibara | SHUHA-8/DUCULA | Ethiopia | 2015 | ICARDA |
| Sandal-4 | CLEMENT/ALD'S'//ZARZOUR/5/AU// KAL/BB/3/BON/4/KVZ//CNO/PJ62 | Eritrea | 2014 | ICARDA |
| Quafza-32 | SHA5//CARC/AUK/3/VEE#5//DOBUC'S' | Eritrea | 2010 | ICARDA |
| Kenya Eagle | EMB16/CBRD//CBRD | Kenya | 2011 | CIMMYT |
| Robin | BABAX/LR42//BABAX*2/3/TUKURU | Kenya | 2011 | CIMMYT |
| Kenya Kingbird | TAM200/TUI/6/PVN//CAR422/ANA/5/ BOW/CROW//BUC/PVN/3/YR/4/TRAP#1 | Kenya | 2012 | CIMMYT |
| Kenya sunbird | ND643/2*WBLL1 | Kenya | 2012 | CIMMYT |
| Lacriwhit-7 | CROW'S'/BOW'S'-3-1994/95//TEVEE'S'/ TADINIA | Nigeria | 2014 | ICARDA |
| Lacriwhit-8 | CHAM4/SHUHA'S'/6/2*SAKER/5/RBS/ ANZA/3/KVZ/HYS//YMH/TOB/4/BOW'S' | Nigeria | 2015 | ICARDA |
| Norman | BABAX/LR42//BABAX | Nigeria | 2015 | CIMMYT |
| Khidaiwi | KAUZ//MON/CROW"S"/4/SERI.1B//KAUZ/ HEVO/3/AMAD | Sudan | 2018 | ICARDA |
| Al-Shibaik | DEBEIRA/4/KAUZ//ALTAR 84/AOS/3/ KAUZ | Sudan | 2018 | ICARDA |
| Jawahir | SHUHA-//NS732/HER | Sudan | 2018 | ICARDA |
| Salah | HUBARA-3*2/SHUHA-4 | Sudan | 2018 | ICARDA |

self-pollinating nature of the wheat crop have contributed to the low participation of the private companies in wheat seed sector which, in turn, contributes to the low rate of variety replacement. The varietal replacement rate measured by the average age of varieties in farmers' fields and average annual seed renewal rate measured by farmers regular purchase of certified seed remain low, with over 10 years and less than 20 per cent, respectively (Bishaw *et al.*, 2016). It is, therefore, important to strengthen the seed system in SSA through capacity development, formulating and implementing stable policy frameworks; encouraging participation of private sectors through incentives; and improving the marketing, information and transportation infrastructures.

## 5. Future prospects

Wheat consumption in SSA has increased over years because of population increase, change in food habits and rapid urbanization, causing a huge gap between local wheat production and demand which, in turn, forces countries to rely on import by incurring millions of dollars from their annual budget. However, the import option is not always easy and reliable, as it depends on the availability of wheat in the global market, ability of SSA countries to compete and buy in times where there is a price-shock because of 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 increasing cost of production. Recent studies on the profitability and potential of wheat production in Africa have indicated that most of the countries in SSA have a huge potential to produce wheat economically and achieve food security. For the realization of this potential, we recommend the following major points.

### *5.1 Developing and adopting climate smart wheat technologies*

Associated to climate change, it is evident that water shortage becomes a major limitation to wheat production even in the irrigated areas of SSA along with heat stress. It is, therefore, important to develop climate smart wheat varieties combining high yield potential and disease resistance with tolerance to drought and heat stresses to produce more grains per drop of water. Furthermore, climate smart technologies such as improved water harvesting techniques, drip irrigation, conservation agriculture, fertigation and site-specific nutrient management need to be implemented and promoted to enhance sustainable wheat production. Most of the SSA countries lack institutional capacity, and their investment in agricultural research is very low. As a result, efforts in these countries shall focus on enhancing the capacity of national research and development institutions to select and adapt appropriate technologies, and in promoting the growth of local suppliers of key inputs and information.

### *5.2 Application and utilization of integrated pest management practices*

The prevalence of diseases and pests, especially in the highlands of Eastern Africa, is a major limiting factor to wheat production. Development and deployment of varieties with resistance to the major diseases (rusts, septoria, fusarium, etc.) is the most economical, socially acceptable and practical method to control wheat diseases, as it is friendly to the environment. However, the resistance of varieties collapses shortly after its deployment, especially when the resistance of the varieties is due to single major gene. Integrated Pest Management (IPM) which combines the use of resistant varieties along with chemical, cultural, physical and biological tools in a way that minimizes economic, health and environmental risks is a sustainable approach to managing pests such as diseases, insects and weeds. However, promotion and implementation of IPM programs require a higher degree of commitment and awareness creation from policymakers and extension agents.

*5.3 Establishing robust seed systems*

Development of improved varieties is not an end by itself unless these varieties are multiplied and marketed to farmers efficiently and timely and make impact on the livelihoods of farmers. To this end, establishment of efficient and effective seed delivery systems are critically important. However, most of the national seed systems in SSA are limited in capacity for seed production, processing and marketing with broad range of constraints including weak policy and regulatory frameworks; inadequate institutional and organizational arrangements compounded by farmers' difficult socio-economic circumstances. Constraints in availability and access to early generation seed (breeder, pre-basic and basic seed) from NARS and production and marketing large volume of certified seed through partnership with public or private sector remain critical. Establishing seed units for EGS production within NARS and providing the necessary support in physical, human and financial resources would alleviate some of the critical bottlenecks. It is, therefore, crucial to assist NARS and development agencies in establishing robust national seed system through capacity development, establishing fast-track variety release systems, participatory demonstrations and accelerated seed multiplication of newly released wheat varieties to ensure fast replacement of existing vulnerable commercial varieties (Bishaw *et al.*, 2016). Protecting the intellectual property rights of innovation in variety development and seed delivery may stimulate private sector investment as shown elsewhere in some African countries.

*5.4 Establishing and promoting enabling policies and working environments*

Favorable and conducive government policies are the founding blocks for any sustainable agricultural production. Government subsidies to agricultural inputs such as improved seed, irrigation water and chemicals encourage farmers to adopt improved wheat technologies and increase wheat production. Furthermore, creation of adequate infrastructures and marketing systems is of paramount importance for having a successful and competent wheat industry at national and regional levels in SSA.

*5.5 Strengthening public-private partnership and networking*

To address the many challenges facing wheat production, partnership and networking among international, regional and national public and private sector institutions is critically important, as it has been witnessed in the International Wheat Improvement Network (IWIN) and currently the WHEAT CRP, an alliance of international Centers (CIMMYT and ICARDA), NARS, Universities and Regional Institutions. The recent partnership of the CGIAR centers, NARS and the African Development Bank (AfDB) through its SARD-SC (Support to Agricultural Research for Development of Strategic Crops in Africa) program is another successful example of collaboration and networking. The SARD-SC wheat project for Africa led by ICARDA in partnership with CIMMYT and the national programs has played a significant role in the development and promotion of wheat varieties along with improved agronomic practices in 12 low-income SSA countries. Such similar collaborations and partnerships among different stakeholders need to be established and strengthened to develop and promote wheat technologies in SSA efficiently and sustainably.

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