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Beyond wheat imports: Sudan's local climate-resilient crops as the staple foods of tomorrow

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Beyond wheat imports: Sudan's local climate-resilient crops as the staple foods of tomorrow

Feasibility and demonstration study

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Summary

Since 2023, there is a civil war ongoing between two rival factions of the military government in Sudan. The civil war in Sudan has resulted into displacement of millions and has brough nearly 25 million people in need of humanitarian assistance. The conflict disrupted Sudan’s agri-food economy, further declining the already low agronomic and economic productivity, inter-country trade and comes on top of changing climate conditions.

While Sudan has a rich cereal and bread tradition based on local crops, the consumption of white bread from imported wheat rapidly increased in the last decades. The increasing import dependency constrains the development of local cereal value chains and economic activities. Stimulating the processing of locally produced climate resilient crops into nutritious staple food products can be an incentive for local economic activities, provide living income and increase food and nutrition security. The Netherlands Enterprise Agency (RVO) in collaboration with the Embassy of the Kingdom of the Netherlands (EKN) in Sudan commissioned this feasibility and demonstration study to Wageningen University & Research.

The main objective of this study was to test the economic and technical feasibility of using local crops to produce Sudanese staple foods. For the economic feasibility assessment desk research was done to understand the sector dynamics and to obtain secondary price data. Also in-depth interviews were done with various actors: private sector, experts and enabling stakeholders. The collected prices were used to make economic feasibility calculations regarding improved recipes for locally produced bread that contain more locally produced crops. The technical feasibility was done by demonstrating the potential of selected local crops to replace imported refined wheat flour in some Sudanese bread type products like baladi, kisra, ghurassa and aceda. This was performed by an exploratory co-development activity with Sudanese companies in Egypt.

The results of this study show that nutritional and attractive Sudanese staples can be made based on local, climate-resilient crops. Wholegrain sorghum and millet flour can be used to replace imported wheat flour in Sudanese baladi bread, when using psyllium as a functional ingredient. Whole cowpea flour (and other pulses) can be included for further nutritional improvement, by increasing the protein content, specifically lysine, as well as adding important micronutrients.

The economic feasibility is positive, since the local crop mix is lower in cost compared to local wheat flour as well as to imported wheat flour on the domestic market. However, these domestic prices are substantially higher compared to that of refined wheat flour on the international market, which will probably favour companies with access to international trade to keep importing wheat.

Besides the technical and economic feasibility, the developed products fit well in local traditions of Sudanese foods, fermentation techniques and traditional taste and flavours of Sudan. Wholegrain flours of local climate resilient crops have potential to strengthen the local food system resilience in Sudan. Since the research of this study was exploratory, it is recommended to validate the findings prior to start implementation and scaling this innovation in Sudan. Validation activities should engage key stakeholders - farmers, millers, bakeries, and consumers - to assess incentives and ownership, as well as engaging the Sudanese national mandated entities. New or ongoing development programmes in Sudan or a public-private partnership could be instrumental in organizing a pilot study to validate the approach commercially, ensuring practical feasibility before broader implementation. Such a pilot study should include a market survey to ensure consumer acceptance. In each case, also the spatial diversity of Sudan needs to be considered well, in respect of the diversity in agricultural (sourcing), infrastructural (roads, market linkages, industrial environment, etc) and cultural (demand, preferences) differences throughout Sudan.

1 Introduction

1.1 Background

Since 2023, there is a civil war ongoing between two rival factions of the military government in Sudan. The civil war in Sudan has resulted into displacement of millions and brough nearly 25 million people in need of humanitarian assistance. The conflict disrupted Sudan's agri-food economy, further declining the already low agronomic and economic productivity, inter-country trade and comes on top of rapidly changing climate conditions.

While Sudan has a rich wholegrain cereal and bread tradition, the consumption of white bread from imported wheat rapidly increased in the last decades, mainly driven by population growth, urbanization and changing consumer preferences. Wheat intake is 530 calories/person/day, accounting for over 20% of the diet. Besides this nutritional shift towards refined wheat, the increasing dependence on imported wheat, which is now 85% of the domestic demand, makes Sudan food supply vulnerable for disruptions and the increasing costs in foreign exchange with an depreciating local currency. Most importantly, it constrains the development of local agri-food value chains and economic activities. Reducing the dependence on imported food and stimulating the agronomic production of diversified climate resilient crops is seen as an important pathway to a more resilient food system. The pre-assumption of this study is that stimulating the processing of locally produced, climate resilient crops into nutritious wholegrain staple food products can be an incentive for local economic activities, provide living income, and increase food and nutrition security.

Through the Nutrifoods project (www.wur.eu/nutrifoods), WUR developed versatile formulations based on mixed local climate resilient crops to allow production of affordable, nutritious and attractive bread-type products, like for instance chapatis in Uganda (Noort and Renzetti, 2023). In this project we tested the feasibility of this approach in the context of Sudan, as a potential intervention for enhancing the use of local climate resilient Sudanese crops into staple food production. The results and recommendations of this study will not immediately change the availability and affordability of food in Sudan, but should be relevant for the current situation, as well as for longer term developments after the conflict.

1.2 Objectives

The objectives of this study are to:

- Evaluate the potential of local climate resilient crops to strengthen the local food system resilience in Sudan and the possibility for scaling this innovation in existing development programmes in Sudan.
- Demonstrate the potential of selected local crops to replace imported refined wheat flour in some Sudanese bread type products.

2 Methodology

2.1 Desk-research and interviews

To test the economic and technical feasibility of local crops to produce Sudanese staple foods, the project evaluated the opportunities and bottlenecks of local crops for production of food products in Sudan, using a simplified food system approach. This activity comprised a combination of desk-research and interviews with various actors and stakeholders in Sudan. Interviewees have been identified and contacted via the existing network of the Dutch Ministry of Foreign Affairs (MoFA), the Embassy of the Kingdom of the Netherlands (EKN) to Sudan, the Conflict Sensitivity Facility (CSF) and Wageningen University and Research (WUR). Stakeholders with ongoing programmes and activities in Sudan have been actively involved in providing resources (e.g. data) and connections of relevance to this project. A list of interviewed or consulted actors and stakeholders is included in Annex 1.

To evaluate the potential of climate resilient crops, desk research and interviews were done to understand the sector dynamics and to obtain price data. Semi-structured interviews were done with various actors: private sector representatives, sector experts and enabling stakeholders such as development organizations. In this way the availability and current use of local crops in Sudan, their cost and opportunities for increasing local sourcing were identified (Chapter 3). Furthermore, we gained an understanding of the Sudanese milling and baking industry, and their capacities and possibilities to increase the use of local crops. An overview of current staples available at consumer market, their nutritional values, product properties, distribution and prices is also provided. The collected prices were used to make economic feasibility calculations regarding improved recipes for locally produced bread that contain more locally produced crops (Chapter 6).
The second aim was to demonstrate the potential of selected local crops to replace refined wheat flour in various Sudanese bread type products. Co-development work was performed by WUR and DAL Food Group, in the test-baking facility of Five Star Flour Mill, in Suez, Egypt, from 12-14 November 2024. During the desk-research and interview phase local crops of interest to replace imported wheat were pre-selected, based on availability (see Section 3.10), climate-resilience, nutritional composition, (expected) technological functionality in different Sudanese breads, cost, etc. Three sorghum cultivars and millets were sourced by DAL foods from Sudan, and representative ingredients were sourced in Egypt or by WUR from other African countries. The technological functionality of these crops was tested in various Sudanese bread (ghurassa, kisra and baladi) during 3 days of co-development work between WUR and DAL foods in an exploratory way (Chapter 4). The experiments were planned and performed based on experience, not by an balanced experimental design. Therefore, dough and bread quality assessments were subjective and qualitative.
Finally, the results were also tested in real-life in 1 Sudanese small bakery in Boulaq, Egypt, where many Sudanese live. We also visited some other Sudanese SME bakeries to ask their opinion about the local crop based product developed (Chapter 5).

2.2 Conflict sensitivity

In view of working with Sudanese actors and the collaboration with private sector in Sudan during the ongoing conflict the following precautions were taken:

- The project will not finance actors for their contribution to this project;
- All results, including all results from co-development work, will be publicly disseminated;
- Gain external conflict sensitivity advise to check our blind spots and learn how we can avoid any unintentional contribution to the conflict in Sudan.

We gained advice though the CSF (csf-sudan.org) who provided practical tips and advice for the design of the project, related to conflict sensitivity principles. The following advice was provided and implemented in the project activities:

- Engage with local universities as well, besides private companies;

- Consider the decentralization of food systems in Sudan: include stakeholders in Darfur and the South of Sudan instead of only the East and North;
- Be aware of the different food cultures in Sudan: take advice from Sudanese food researchers.

2.3 Limitations of the study

The ongoing conflict in Sudan has a large impact on the activities of this project, and limits the representativeness of the outcomes. As it was not possible to perform the research in Sudan, we mostly relied on desk-research, online interviews and working with Sudanese actors in Egypt. However, all interviewed stakeholders demonstrated a high level of cooperation and provided valuable insights.

As we closely collaborated with large private sector companies like DAL foods and SAY group, we avoided bias by involving as much as possible smaller companies or their perspectives as well. The security situation in Sudan affects the stability of local companies, especially SMEs in Sudan are hampered to collaborate with in terms of connectivity and instability. We interviewed several NGOs working with small local businesses as secondary sources. Furthermore, we visited and interviewed Sudanese SME bakeries in Egypt.

Obtaining detailed economic data has been particularly challenging and the representativeness of market data, including prices and availability, is significantly impacted by the ongoing instability. On top of this, as of January 30 2025, we were unable to access FEWS NET data due to the USAID funding freeze, which prevented us from accessing key (historic) market data such as price information from different markets in Sudan.

Our findings and recommendations aim to be relevant both for the current situation and for the longer-term recovery post-conflict. The conflict has profoundly influenced market dynamics, food prices, and overall supply chains. Where possible, we gathered data from both pre-conflict periods (2016–2021) and the current situation to better assess the impact of the conflict. While interviews provide valuable insights, the information remains largely anecdotal.

3 Staple food production in Sudan

3.1 Introduction

This chapter describes the agriculture sector in Sudan. It evaluates the opportunities and bottlenecks of the selected local crops for food production, focusing on the availability, costs and the economic feasibility of crops such as sorghum, millets, pulses, and other locally cultivated staples. We compare these local crops to imported wheat, which dominates the bakery sector. In addition, we consider the current staple crops in consumer markets in terms of nutritional value and product properties.

The current conflict is a serious threat for food security in the country, affecting the availability and affordability of food, and affecting the livelihood of millions. Prices of many commodities have increased significantly since the start of the conflict.

3.2 Agriculture in Sudan

Sudan has a diverse agricultural sector, with large differences in food crops and agricultural practices depending on the climate and soil conditions (Figure 1) throughout the country and the availability of irrigation (Ali et al., 2022). Overall, the main food crops grown in Sudan include:

- Cereals: sorghum is the most widely grown staple crop, used for food and fodder and produced across the country. Millets is particularly grown in the arid and semi-arid regions in the West. Wheat is mainly cultivated in the irrigated schemes of northern and central Sudan along the river Nile. Also small quantities of other cereals including maize are grown, both in irrigated and rainfed areas.
- Oilseeds and legumes: Groundnuts (Peanuts) are a significant crop both for food as well as cash crop for export. Sudan is one of the top producers of sesame (simsim) globally, which is used for oil extraction, as food and also produced for export markets. Sesame has grown in the last decades into the largest agricultural export product of Sudan. Soya is a new crop in Sudan, farmers don't yet know it and the market demand is uncertain.
- Pulses: Beans, including cowpeas, pigeon peas, chickpeas, faba beans and lentils are grown, especially in Kordofan and Darfur in rainfed systems.
- Roots and tubers: Although not a traditional indigenous crop in Sudan, sweet potato is grown increasingly. It is not as common as in Egypt yet, but is appreciated and consumed as a vegetable. It is currently not processed into flours in Sudan.
- Fruits and vegetables: Important fruits are mangoes and watermelons (fruit, water and seed) and important vegetables are onions, tomatoes, okra and eggplants.
- Other: Sudan is a leading producer of gum Arabic, a water-soluble gum obtained from acacia trees. Other important crops are cotton (providing cotton seed meal and oil as side products relevant for food), sugarcane and hibiscus. Alfalfa production for animal feed is very popular as a rotation crop with cereals in irrigated mechanized systems. It stands out by its high protein content, is highly adapted to hot conditions, and grows abundantly with regular irrigation. It allows high yields and can be harvested monthly as a forage hay (sun-cured).

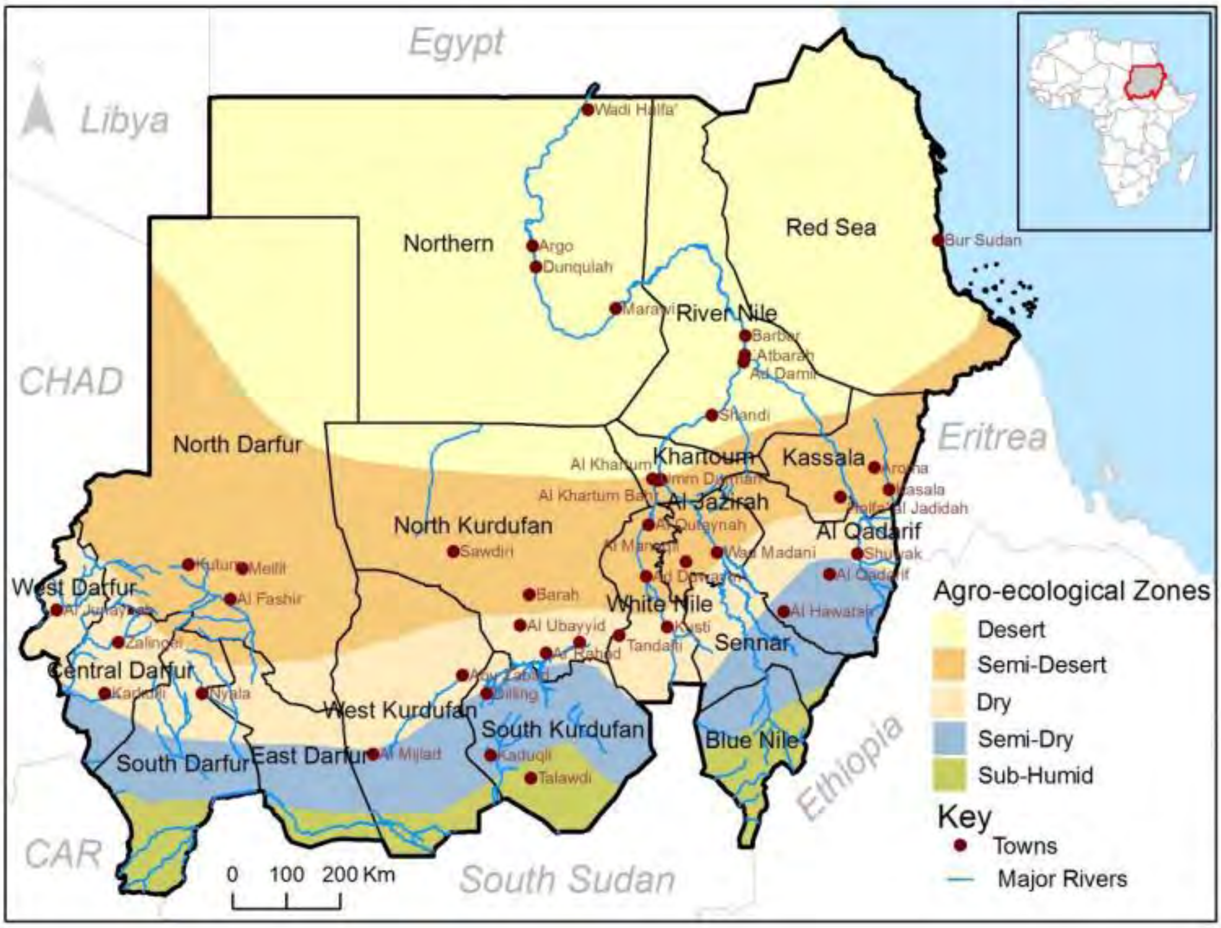

Figure 1 Map of agri-ecological zones of Sudan (MoAF, 2021)

Agriculture in Sudan is largely rainfed (Figure 2), though there are extensive irrigation schemes, such as the El Gezira Scheme in Gezira State, which support food production. The agriculture sector is crucial for food security and the economy, being the main source of livelihood and income for 60-80% of the population (FAO, 2023). We identify 3 distinct subsectors in Sudanese agriculture: commercial farming, including mechanized irrigated farming and semi-mechanized rain-fed farming; traditional rain-fed subsistence farming and livestock farming (pastoralism).

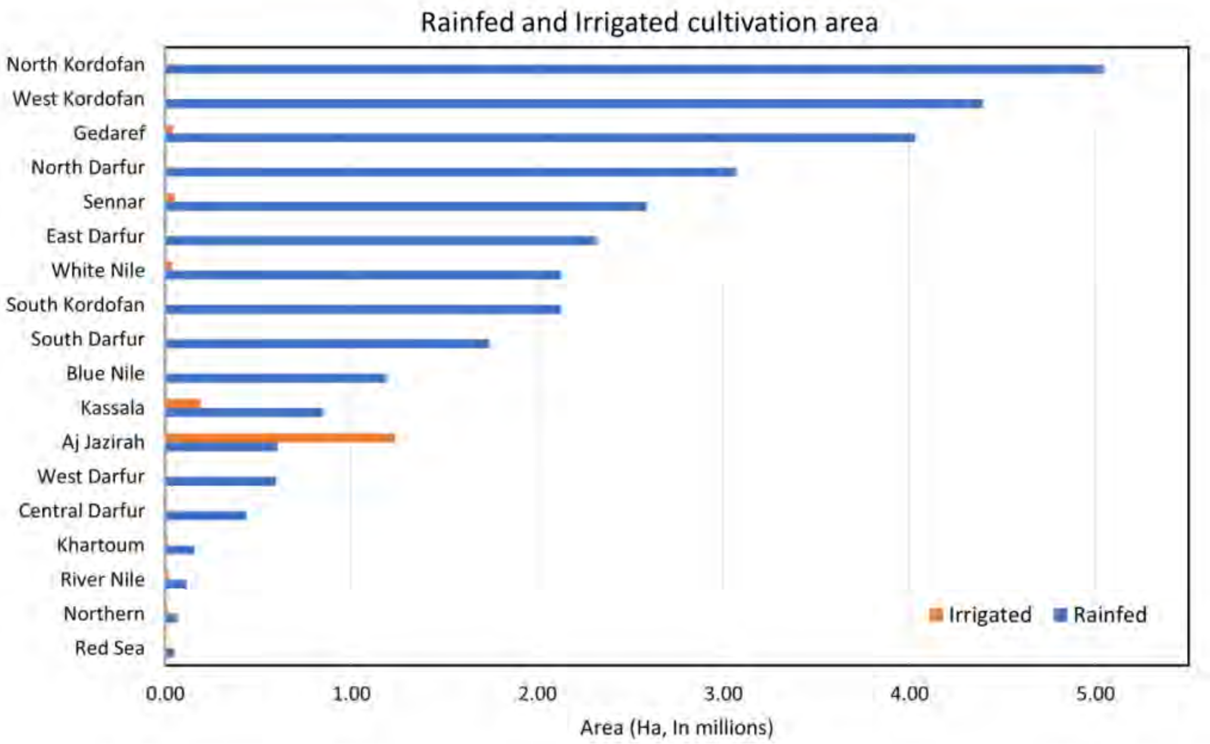

Figure 2 Rainfed and irrigated agricultural area of Sudan by states (Kumar 2023)

3.2.1 Commercial mechanized irrigated and rain-fed production

Irrigated areas along the White and Blue Niles account for about 5% of the total arable land of Sudan. It includes the El Gezira scheme between the two branches of Nile and one of the world's largest irrigation schemes encompassing about one million hectares of land. Sudan's irrigated agriculture is dependent on abundant supplies of water from the two main branches of the Nile.

An important challenge is that over time land intensification, silt accumulation, and increased water use has caused the performance of the El Gezira Scheme to deteriorate (Goelnitz and Al-Saidi, 2020). Rich farmers are reported to practice a sophisticated version of traditional shifting cultivation: they farm an area intensively with government-financed equipment for a few years but then move on to more attractive virgin land when yields decline. This practice has led to soil erosion and even to desertification in some areas. The main crops grown in the irrigated sector include sugarcane, cotton, sorghum, groundnuts, wheat, legumes, spices, vegetables, fruits and green fodders like alfalfa (FAO, 2024).

The (semi)mechanized rain-fed farming occurs in a broad belt running from the northeastern portion of the country (Kassala) to the south-southwest (West-Darfur) along the agro-ecological lines of Figure 1. It covers about 6.7 million hectares and runs mainly through Kassala, Gedaref, Blue Nile, Sennar, White Nile and South Kordofan states and receives annually more than 500 mm of rainfall on average (FAO, 2024). The mechanization is limited to land preparation, sowing and, only partially, to harvesting (sometimes also by using combined harvesters), while other agricultural operations are carried out manually. This broad belt of mechanized agriculture is called the granary of the country, with sorghum accounting for about 80% of the total cultivated land and for about 45% of the country's requirements (FAO, 2024).

Both the irrigated areas like as well as the mechanized rain-fed agriculture rely on mono-cropping. The decline in multi-cropping is mainly due to mechanization.

Rainfed areas typically have only 1 harvest per year, whereas irrigated areas have 2 growing seasons, with sorghum as summer crop. Also in the North there is a summer and winter harvest, with wheat as a winter crop and pulses as summer crop.

3.2.2 Traditional rain-fed subsistence farming

Much of the country's population is engaged in traditional rain-fed subsistence farming, generating both income from cash crops and produce foods for their own consumption. This sector encompasses most of the arable land by far and occupies the largest number of farmers. Many such farmers live in the low-rainfall savannas of West and South Sudan, growing crops like sorghum, millet and groundnuts.

Many households also keep some livestock, in particular donkeys, goats, poultry, cattle, and sheep. Since the conflict resulted in mass migrations, local communities are changing and social systems as well. For instance, land formerly used for agriculture by farmers that flew, are becoming available and used by pastoralists. The social system of shared communal land and use system has been disrupted. Absence or weak institutions and unclear ownership are leading to conflicts between farmers and pastoralists over the use of the land.

Small farmer practices are low-yielding. They use very limited or no inputs as these are too expensive and they lack access to financing. They keep their seeds of local varieties for planting. Also, they don't own machinery, causing unfavourable timing of their practices. At the right time, machines are not available or too expensive, and they will perform the action too late. Small farmers are rather independent and have weak collaborations, and poor access to markets. They rely on local markets and traders, causing limited revenues and limited investment power for the next season.

Interestingly, in the relative dry rainfed areas the agronomic system is by tradition a multi-cropping system. For example, millet is planted together with groundnuts or sesame, cowpea, hibiscus and watermelon. These synergies are based on the different rooting systems, with millet having more shallow herbaceous roots, and sesame with deep tap roots. Especially in these areas in Sudan the farming system also uses combinations with trees like Acacia. Another example is the use of pulses like pigeon peas that are planted as fencing around the plot.

3.2.3 Pastoralism

The entire country of Sudan, but particular the dry savannas, have a strong pastoralist tradition, with both nomadic and sedentary herds. The commercial exploitation of livestock only truly began in the 1970s, and livestock is now an important agricultural export product (mainly to Egypt, Saudi Arabia, and other Arab Countries), contributing around 60% of the total agricultural revenues (C-Adapt, 2016) Despite this large contribution to GDP the majority of this revenue depends on smallholders or pastoralist producers.
Due to erratic seasonal rains and conflict induced migration, availability and accessibility of pasture lands is under pressure and conflicts between farmers and herders have been reported. The major problem faced by pastoralists is the loss of rangeland due to the expansion of mechanized farming. The traditional practice of farmers allowing herds to graze crop residues, with animals simultaneously fertilizing land, is declining as farmers prefer to sell their residues for cash (FAO, 2024).

3.3 Climate change and resilience of crop production

Climate change projections for Sudan show substantial increases in temperature (+1.5°C to 3°C), whereas there is no clear projected trend in mean annual rainfall for Sudan (C-Adept 2016). The changes will mean higher temperatures, reductions in water availability and continued year-to-year variability in a country already highly sensitive to such changes (C-Adept 2016). Hence, climate changes are expected to further increase food insecurity across Sudan. Climate adaptation measures should focus on reducing sensitivity, improving resilience to variability and extremes, and improving heat tolerance and water efficiency in agricultural production. In practice, it is expected that the boundaries of the current agro-ecological zones in Sudan shift gradually southwards, and farmers should consider the choice of (diversity of) crops they plant. Enhanced uptake of Climate-resilient crops should be encouraged. Climate-resilient crops are defined as crops that are adapted to the environment, more resistant to abiotic (drought, heat) and biotic stresses (fungi, insects) and hence can grow with fewer inputs. An overview of cultivation requirements under climate stresses relevant to Sudan is given in Table 1. In this study, we focus on crops as they are currently cultivated and available in Sudan, and don't evaluate or discuss other strategies for climate-change adaptation like breeding of specific cultivars (e.g. heat-tolerant wheat) or improved cropping systems.

Table 1 Overview of cultivation requirements under climate stresses relevant to Sudan for the major commodity cereal crops (wheat, rice, maize) in comparison to selected Climate-Resilient Crops currently cultivated in Sudan (from Noort et al 2022).

Common name	Proper name	Type of Crop	Cultivation habitat requirements	Tolerance to high temperatures	Tolerance to water stress and drought	Other beneficial agronomic and crop attributes
Major crops						
Bread wheat	*Triticum aestivum* L.	Cereal grain	Daily maximum temperature 22–30 °C and 600 mm rainfall. Ideally cool and moist with dry harvesting season. Loamy to sandy loam soils	Moderate	Poor drought tolerance	
Dryland (upland) rice	*Oryza sativa* L.	Cereal grain	Minimum temperature > 15 °C. Rainfall 800–900 mm. Soil with a minimum of 15% clay	Moderate	Very poor	
Maize	*Zea mays* L.	Cereal grain	Daily maximum temperate ≥ 23 °C. Rainfall 500–800 mm. 10–30% clay soils	Moderate	Poor drought tolerance	C4 plant. The highest yield among cereals under optimal conditions
Climate-resilient crops						
Sorghum	*Sorghum bicolor* (L.) Moench	Cereal grain	Daily optimal maximum temperature 27–30 °C. Rainfall 450–650 mm. Prefers heavier soils than maize	More tolerant than maize	Drought-tolerant. The highest water use efficiency among cereals. Can withstand waterlogging	C4 plant. Valuable fodder crop.
Pearl millet	*Pennisetum glaucum* (L.) R. Br.	Cereal grain	Daily optimal maximum temperature 23–30 °C. Rainfall 450–650 mm. Sandy or light loam soils	Highly tolerant	Less tolerant than sorghum	C4 plant. Valuable fodder crop.
Cowpea	*Vigna unguiculata* (L.) Walp	Grain legume	Daily optimal maximum temperature 30 °C. Rainfall 400–700 mm. Prefers sandy soils but can be cultivated on a range of soils	Very tolerant	Drought-tolerant but prefers regular rainfall. High tolerance to waterlogging.	Fixes atmospheric nitrogen. Intercropping provides nitrogen to another crop. Used as green manure. Leaves are used as a vegetable.
Sweet Potato	*Ipomoea Batatas*	Starchy tuber	Rainfall 530–800 mm.	Tolerant	Drought-tolerant	C3 plant, but drought tolerant. Relative high salinity tolerant. Leaves are used as a vegetable.

Anticipating on Sudan's current and future climate challenges for food production, in this study we mainly focus on the opportunity to adapt though crop selection. Given the poor water efficiency and poor drought tolerance of bread wheat, rice and maize, shifting to climate-resilient crop production and use should be stimulated. Wheat is among the main crops produced in Sudan, and it should be noted that the production is concentrated in irrigated fields in the North along the Nile. Also, a substantial share of the wheat production in Sudan is durum wheat, which is more tolerant to high temperatures and drought, although yields are negatively affected by these climate stressors (Grosse-Heilmann et al, 2024). Durum is not well suitable for bread production, but particular for pasta (vermicelli is a popular staple food in Sudan). Durum production in Sudan is not fulfilling the domestic demand, hence shifting production from bread wheat to durum wheat production could be one of the climate-change adaptations.

However, for the majority of Sudan's agricultural system dominated by rain-fed cultivation in (semi-)arid conditions with further increasing temperatures, production of sorghum and millet in combination with legumes should be promoted. For stimulating and increasing the production of these crops, enhancing demand and higher value applications could be effective incentives.

3.4 Production and trade of wheat, sorghum and pulses

Table 2 and Figure 3 provide an overview of Sudan's production and trade, based on FAO and USDA data, detailing key metrics for pulse and cereal crops. It offers insight into the harvested area, production volume, yield per hectare, and trade flows, highlighting Sudan's crop production and dependencies on imports.

In the cereal category, the table lists maize, millet, wheat, and sorghum, with sorghum occupying the largest area at 7,000,000 hectares, reflecting its role as a staple crop in Sudanese diets. Sorghum also dominates production, reaching almost 6 million tons. However, the total production of sorghum has decreased since 2022. Also yield has decreased since then from 2.3 tons per ha to 1.6 tons per ha. Wheat, however, records the highest yield among cereals at 1.70 tons per hectare, though its overall production remains limited compared to the vast quantities imported. Sorghum also has some records of export, with 31,577 tons valued at 11.5 million USD, suggesting that it even finds some demand outside Sudan's borders (e.g. the Emirates are still importing from Sudan, according to interviewed private sector stakeholders). Wheat, on the other hand, is overwhelmingly dependent on imports to meet (urban) consumer preferences.

The table shows that Sudan imported 1,440,310 tons of wheat, with an import value of 560.9 million USD, underscoring a significant dependency on foreign wheat to fulfil domestic demand. Overall, Sudan harvested 9,814,448 hectares for cereal production, yielding a total of 7,456,084 tons with an average yield of 0.76 tons per hectare. Total cereal exports amount to 33,955 tons, while imports reach 1,682,795 tons, costing the country 665.5 million USD, emphasizing a heavy reliance on cereal imports, particularly for wheat.

For pulses, the table includes dry beans, broad beans, chickpeas, cowpeas, and other unspecified pulses. Pulses, and in particular cowpeas are important crops for smallholder farmers. Cowpea covers the largest harvested area at 292,075 hectares, indicating their importance in Sudan's pulse production. Cowpea is in Sudan, alike in many African countries, in particular a subsistence crop and is traded on domestic markets. Other pulses like broad beans and chickpeas have a more prominent (international) market demand, and are important culinary components, e.g. for making humus and falafel. Among pulses, broad beans come second with a production of 172,987 tons, reflecting high productivity in terms of yield. In terms of trade, chickpeas are the most exported pulse, with 22,679 tons shipped abroad, valued at 12 million USD, signalling some demand in international markets. Chickpea demand is rising due to the trend for plant based protein rich crops and is a highly demanded crop in the Middle-East, having strong trade relations with Sudan. Conversely, broad beans show the highest import quantities, at 19,902 tons, with an import value of 13.2 million USD, indicating a domestic shortfall despite significant local production. Overall, Sudan's total pulse production covers 455,768 hectares, yielding 559,093 tons, with an average yield of 1.23 tons per hectare. While the country exports a notable 71,046 tons of pulses, it also imports 135,248 tons, costing 142.6 million USD, underscoring a reliance on imports to meet domestic demand for certain types of pulses.

In summary, the data illustrates Sudan's strong reliance on imported cereals, especially wheat, to meet urban domestic demand. Despite high production levels of sorghum, a traditional staple, wheat imports are substantial. For pulses, the data presents a mixed picture of self-sufficiency and import dependency, with notable imports of specific types, like broad beans. Yield differences across crops suggest potential areas for productivity improvements, particularly in cereals like sorghum, maize and millet, which exhibit relatively low yields connecting to their production primarily as subsistence-farming in not-irrigated areas. Comparing the current yields of sorghum in Sudan (0.58T/ha) with Ethiopia (2.76 T/ha; both 5-year Average 2019/20 - 2023/24, USDA) reflects the potential for improving the yields of these local crops when investments in the agricultural sector can be made. The reliance on imports for certain staple foods highlights both challenges and opportunities in Sudan's agricultural sector, where domestic production could be enhanced to reduce dependency on external sources.

Table 2 Data on production and trade 2022 (source FAOstat)

Group	Crop	Area harvested (ha)	Production (t)	Yield (t per ha)	Total Export Quantity (t)	Total Export Value (1,000 USD)	Total Import Quantity (t)	Total Import Value (1,000 USD)
Cereals	Millet	2,500,000	1,675,000	0.67	2	3		
	Wheat	280,000	476,000	1.70			1,440,310	560,908
	Sorghum	7,000,000	5,248,000	0.75	31,577	11,445	122,741	48,516
	Cereals, Total	9,814,448	7,456,084	0.76	33,955	12,026	1,682,795	665,506
Pulses	Beans, dry	3,569	12,401	3.47	36	19	175	180
	Broad beans and horse beans, dry	28,749	172,987	6.02	5	14	19,902	13,202
	Chick peas, dry	23,843	96,505	4.05	22,679	11,978	383	401
	Cow peas, dry	292,075	183,520	0.63	24	28	5	29
	Other pulses n.e.c.	107,532	93,680	0.87	125	43	2518	1912
	Pulses, Total	455,768	559,093	1.23	71,046	48,561	135,248	142,594
Potatoes	Potatoes	42,459	520,134	12.25			14,281	13,985
	Sweet potato	34,794	266,986	7.67				

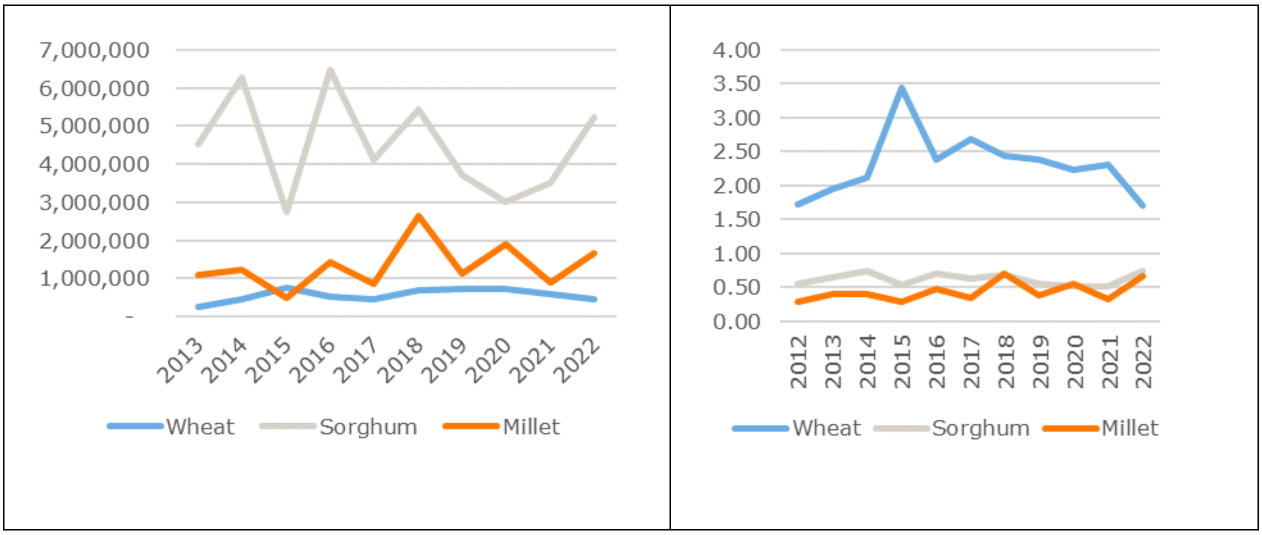

Figure 3 A) Production in tons and B) yield in tons per ha (source FAOstat)

3.5 Availability of local crops

3.5.1 Wheat

Production areas

Domestic wheat production contributes to only about 15% of Sudan's wheat demand for most years. Almost all of Sudan's domestic wheat is irrigated and production is predominantly concentrated along the river Nile (see). The main production area (41%) is in El Gezira state in the Gezira Scheme. Also substantial production can be found in North-Sudan (34%) where wheat is the traditional main staple crop, used for making ghurassa (MoAF, 2021).

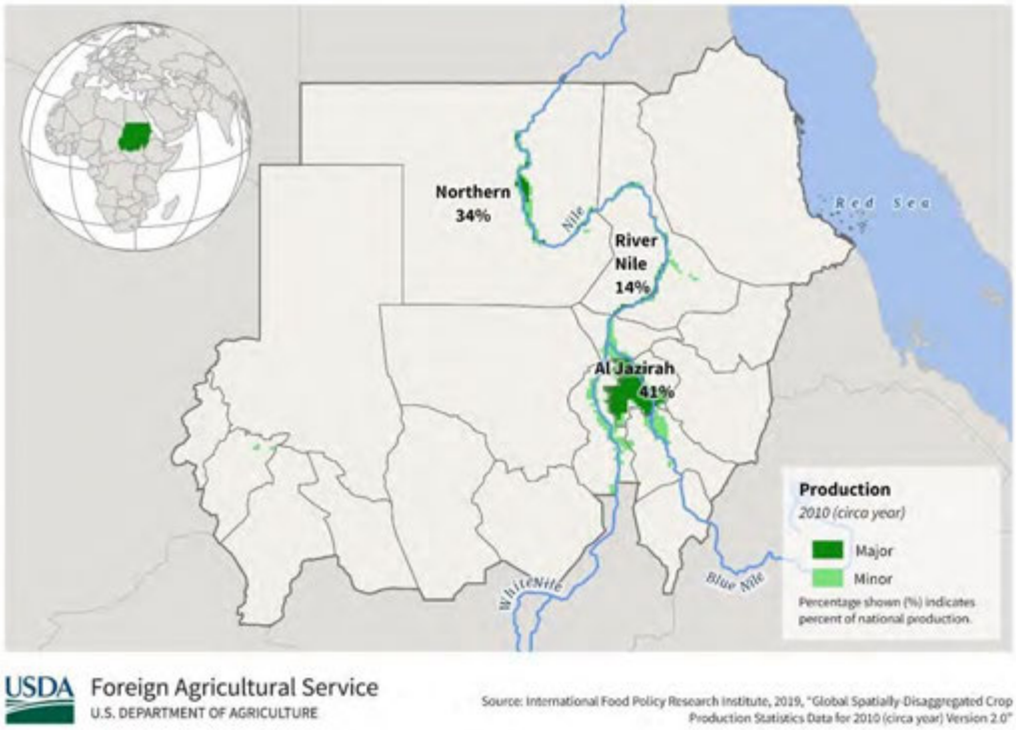

Figure 4 Wheat production in Sudan (USDA, 2024; IFPRI, 2019)

Imported wheat plays a central role in Sudan's food system, driven by strong urban demand for wheat-based products such as bread and other baked goods. Approximately 85% of Sudan's wheat is imported (Abay et al, 2022), making it highly dependent on foreign markets to meet consumer demand. Wheat consumption in Sudan has grown significantly in recent decades, driven by urbanization and the changing diet, with bread serving as a staple for urban populations (Thomas and El Gizouli, 2020). While imported wheat supports food security in the short term, it also places substantial pressure on the country's foreign currency reserves, exposes Sudan to global price fluctuations, and amplifies economic vulnerability, particularly during times of inflation and currency devaluation (Abay et al., 2022).

Value chain actors

The imported wheat value chain is more centralized than that of local crops, only a few key actors are responsible for importing, processing, and distributing wheat. Major milling companies, such as Sayga (owned by DAL food) and Wheata, play a dominant role, importing wheat under subsidies provided by the Central Bank of Sudan (CBS) and converting it into (refined) flour. They operate with a preferential exchange rate, historically offered by the government, allowing them to purchase wheat at lower costs than the open market of imported wheat would dictate, but also at a lower costs compared to locally produced wheat. This subsidized wheat flour is then distributed through a network of flour agents and bakeries across the country, ensuring a steady supply of affordable bread to urban consumers (Abdelaziz et al, 2022).

Economic implications and cost pressures

Sudan has a rich tradition of cereal-based staples made from local crops, including indigenous wheat. However, the country is becoming increasingly dependent on imported wheat for bread production, while local cereals remain largely underutilised for this. As such locally grown wheat is rarely used by bakeries for bread production (see section 3.8). Instead, it is almost exclusively reserved for home preparation of traditional foods such as ghurassa.

Wheat is a cheap source of nutrients, highly available on the global market, and hence importation can lead to improved affordability of food, while freeing-up arable land for higher-value agricultural goods. On the other hand, the domestic cereal production can't compete economically with (subsidized) imported wheat, reducing farmer incomes and discouraging farmer investments in inputs like seeds and fertilizers. For example, when the Sudanese pound depreciates, the cost of imports rises, increasing the price of bread, a politically sensitive commodity. In recent years, the government has attempted to liberalize the exchange rate, which has led to further inflationary pressures on imported goods, including wheat (IPFRI, 2023).

Government subsidies and policy challenges

The Sudanese government has historically subsidized wheat to ensure affordability for urban consumers. This subsidy system operates through preferential exchange rates for importers and price controls on flour and bread. However, this approach is costly and has led to periodic financial crises. In 2018, attempts to reduce subsidies resulted in higher bread prices, sparking widespread protests that contributed to political instability and regime change. While subsidies were reinstated following public unrest, they continue to place a heavy burden on government finances (Thomas and El Gizouli, 2020; Abdelaziz et al, 2022).

In recent years, the government has implemented reforms to tighten subsidy controls and reduce inefficiencies. Monitoring systems, such as the Khartoum Food Security Company (KFSC) and local resistance committees, were established to ensure subsidized flour reaches its intended recipients and to limit black-market diversion. However, these measures have only partially succeeded, as smuggling and market manipulation remain challenges. Achieving greater efficiency in wheat subsidy administration requires more comprehensive data on consumption patterns, enhanced transparency in subsidy allocation, and improved accountability within distribution networks (Abdelaziz et al, 2022).

Food Security risks

Sudan's reliance on imported wheat poses significant food security risks, particularly in the face of global market volatility. When international wheat prices rise or supply chains are disrupted, as seen during the COVID-19 pandemic (Abdelaziz et al, 2022) or the Russian-Ukrainian conflict resulting in global commodity price hikes, Sudan faces severe domestic price increases, which disproportionately affect low-income households. In addition, currency devaluation and inflation exacerbate these risks, making wheat and bread less affordable and accessible (Abdelaziz et al, 2022). Addressing these vulnerabilities requires a strategic rethinking of Sudan's food system to diversify its staple food sources and reduce dependency on imported wheat.

Market

Wheat is the dominant staple in urban areas due to its light colour, soft texture, and modern appeal, which align with the changed urban consumer preferences for bread and baked goods. Subsidies on wheat have historically made it artificially affordable. Before the conflict, most wheat was imported and milled in Sudan. Currently, almost all wheat is imported as already milled flour, mostly from Libya and Turkey. Various stakeholders interviewed, state that urban consumers in Sudan prefer bread made from wheat due to changing consumer preferences. In addition, Thomas and El Gizouli (2020) give the following example "in Sudan, when people are pushed towards towns, they are pushed towards wheat. In 2015, USAID's Famine Early Warning Network (FEWSNET) found evidence that up to 90% of newly displaced people shift from sorghum and millet to wheat bread within a few years of displacement. Evidence for this was found in Nyala, the capital of South Darfur, where displaced people were seen to be trading humanitarian rations of sorghum for commercial bread." They attribute to this that wheat bread is fast food for people working outside the home and a time-saver for the kitchen workforce. However, the price of wheat bread has increased significantly due to the conflict situation and supply chain disruptions.

3.5.2 Sorghum

Production areas

Sorghum stands as Sudan's most crucial crop, both culturally and by production volume. It is a staple across much of Sudan, but traditionally the main staple crop in East-Sudan. Sorghum production is particularly high in regions like Kassala, Gedaref, and Sennar, where it grows well in the rain-fed savannahs, see Figure 5. Also some farmers do apply irrigation. Farmers that apply irrigation are often based in schemes. Sorghum can thrive in Sudan's challenging climate, which is marked by high temperatures, limited rainfall, and frequent droughts. Compared to wheat, which relies heavily on subsidies and irrigation, sorghum requires fewer inputs, making it more accessible and affordable for smallholder farmers. Sudan is one of the largest producers of sorghum in Africa, highlighting its importance not only to domestic food security but also to regional markets, where it serves as human food, livestock feed and, at times, a humanitarian food aid commodity for neighbouring countries. Sorghum's adaptability makes it a strong candidate for expanded cultivation. However, its production is currently limited by a lack of investment in modern agricultural practices.

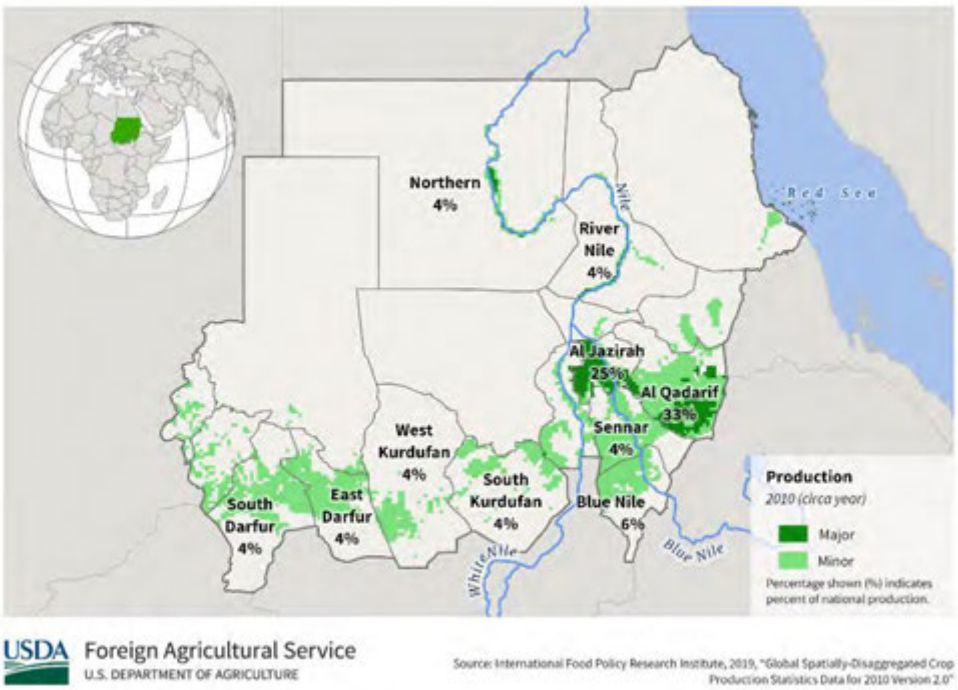

Figure 5 Sorghum production in Sudan (USDA, 2024; IFPRI, 2019)

Value chain actors

Sorghum production in Sudan involves smallholder farmers, medium-scale producers, and large agribusinesses. Smallholder farmers, working on plots between 5 and 50 feddans (1 feddan = 0.42 acres), often face limited access to modern inputs and organized markets. In contrast, larger farms and agribusinesses dominate the value chain, benefiting from better access to land, technology, and financing. Brokers and traders play a crucial role in sorghum marketing, with brokers frequently purchasing directly from smallholders and selling in major urban markets, such as Gedaref's central crop market. Some larger farmers also act as brokers, consolidating smaller farmers' outputs for resale. The processing sector includes small- and medium-sized mills alongside major firms like Sayga Mills, which has a near-monopoly on sorghum flour production for the formal market, distributing it through an extensive agent network across Sudan. Large companies such as CTC Agrochemicals, DAL Agro, and the Arab Sudanese Seed Company supply essential inputs, including machinery, fertilizers, and seeds, with many products imported to meet the demand in Sudan.

Economic and policy constraints

The economic policies surrounding sorghum further limit its market competitiveness. Unlike wheat, which benefits from subsidies and preferential exchange rates, sorghum is taxed, increasing its market cost. This discrepancy has roots in Sudan's urban-rural divide, where wheat is prioritized to satisfy urban consumers who associate it with modern lifestyles. Sorghum, on the other hand, is viewed as a "rural" grain, contributing to its lower demand in urban areas. Government intervention through wheat subsidies has inadvertently set back the sorghum sector, despite its greater adaptability to local conditions, its resilience towards climate-changes and its potential to enhance food security. Examples of these polices are the ban on exporting sorghum (with exception to a few private companies) but also price controlling mechanisms like the Strategic Food Reserves Policy, which stabilizes prices by buying and selling sorghum with a pivot price (fixed price) in times of surplus or scarcity (Sorghum VCA, n.d.).

Addressing this imbalance would require policy reforms that create a more level playing field, where sorghum can compete with wheat in urban markets. This could include targeted subsidies or tax incentives for sorghum production and distribution, especially in regions with high production potential (Abay et al, 2022; Abdelaziz et al, 2022)

Market

A lack of adequate infrastructure limits sorghum's distribution and market reach. Smallholder farmers, who produce much of Sudan's sorghum, often face challenges accessing profitable markets, forcing them to sell their crops at low prices to intermediaries. Additionally, insufficient storage facilities lead to high post-harvest losses, further reducing the financial returns for farmers. Creating efficient supply chains that link rural production areas with urban markets could support a more sustainable and profitable sorghum market. Investment in transport, storage, and processing infrastructure is essential for increasing sorghum's role in Sudan's food system and enhancing food security. Sorghum is mainly used for household use or informal food processors. Integrating sorghum into the commercial baking industry could also help establish it as a staple food option in urban markets, creating additional opportunities for both farmers and food producers.

Sorghum is widely consumed in rural areas and among lower-income groups. However, its darker colour and denser texture make it less appealing to urban consumers accustomed to wheat. Sorghum is abundant and used as both a staple and animal fodder. Sorghum is primarily used for traditional foods like kisra (a type of flatbread) and aceda (stiff porridge) among many more.

Gedaref State is the largest producer of rainfed crops in Sudan, particularly sorghum, sesame (simsim), groundnut and cotton. The state's capital, Gedaref city, hosts the largest sorghum market in Sudan, which sources sorghum not only from Gedaref but also from neighbouring states such as Kassala, Sinnar, Gizera, and Blue Nile. The supply of sorghum to this market plays a critical role in influencing prices throughout Sudan and even in neighbouring countries. Over the past three years, sorghum supply has been on a steady decline, contributing to sharp increases in prices In the 2023/2024 season, sorghum supplies dropped compared to the previous season 2022/2023 and by 24% compared to the five year average. This reduction in supply has been a key factor in the rise in sorghum prices over the past year exacerbating food affordability and food security challenges in the region. Ad-Damazin is another key market and they represents the surplus production area of Sudan and has links with most of the markets in Sudan.

3.5.3 Millet

Production areas

Millets is the traditional staple crop of West-Sudan. It is primarily cultivated in Sudan's rain-fed regions, and well-suited to the arid climate due to it's drought-resistance. Millets are highly adaptable, thriving in regions with minimal rainfall where other grains, such as wheat or maize, may struggle. Alike sorghum, millets contribute significantly to the diet of rural populations, especially in regions like Kordofan and Darfur. See Figure 6 for the different Millet production areas. Millets offer an alternative to wheat, which dominates the Sudanese diet but is dependent on imports and can help diversify Sudan's food system, providing stability against global supply fluctuations (IFPRI, 2023).

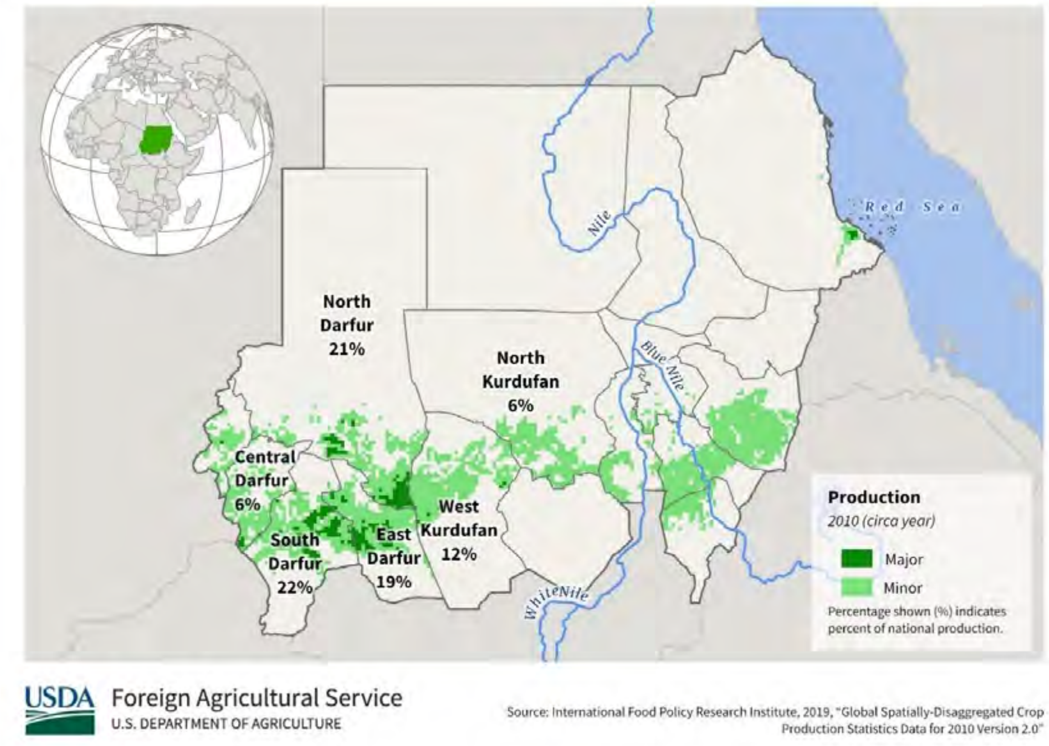

Figure 6 Millet production in Sudan (USDA, 2024; IFPRI, 2019)

Value chain actors

Rural communities in the West often rely on millets for their resilience and nutritional benefits. Approximately one-third of crop-producing households grow millet and this proportion has increased since 2009 (Ali et al., 2022). Whereas sorghum is grown almost equally by poor and non-poor households, millet is grown more predominantly by the poor. Poor households resort to low-risk, low-return subsistence crops. Crops like millet and lentils are grown predominantly to be consumed within the household. Although the market price of millet is substantially higher than that of sorghum, millet production is apparently not very profitable in the current situation.

In addition, the production of millet in the West of Sudan makes it difficult for big formal companies to operate. Millets is relative costly and has limited shelf-life. Sourcing millets by large mills, milling it (at the large mills in Khartoum/East) and distribute and sell it back in the West is not (cost) effective. Hence, Millet depends mainly on informal value chains with small local millers.

Economic and policy constraints

The ability of millets to withstand heat and water scarcity makes them an ideal crop for Sudan’s climate, especially as climate change exacerbates drought conditions. Despite these critical advantages the cultivation of millets remains limited due to inadequate support for smallholder farmers, who primarily grow these crops. Investment in agricultural training, improved seeds, and basic mechanization is often lacking (Abdelaziz et al, 2022).

Market

The market for millets in Sudan is underdeveloped compared to wheat, which receives considerable subsidies and policy support. This lack of government support limits the profitability of millets which, unlike wheat, do not benefit from price guarantees or subsidies. Moreover, market infrastructure is weak, with poor storage facilities and limited transport links that hinder efficient distribution, leading to post-harvest losses and increased costs.

Interviewed stakeholders indicated that millet is mainly consumed in western Sudan and rural areas where it is a traditional staple. It is primarily used in aceda, a thick porridge which is part of the traditional West-Sudanese meal.

3.5.4 Cowpea and other pulses

Production

Cowpea, is a significant pulse in Sudan and predominantly cultivated in the semi-arid regions, including Kordofan and Darfur. These regions are well-suited to cowpea production due to their resilience to heat and water scarcity. Other pulses, such as chickpeas and pigeon peas, are also commonly produced in Sudan, contributing to the diversity of legumes grown. Pulses are commonly drought-tolerant, making them invaluable crops for Sudan's rain-fed agricultural systems. Despite its potential, cowpea cultivation remains largely underutilized, with production primarily concentrated among smallholder farmers who rely on traditional farming methods. These farmers often lack access to modern inputs, mechanization, and financial support, limiting the crop's productivity and market integration (Abdelaziz et al., 2022).

Value chain actors

The cowpea value chain involves several actors, including smallholder farmers, traders, and local processors. Farmers typically sell their produce to traders or intermediaries, who then distribute it to local markets. The absence of large-scale processors and advanced marketing channels currently limits the value added of cowpeas and other pulses. However, this challenge presents a significant opportunity, as the demand from urban markets remains unmet due to the limited capacity of local, small-scale processors.

Economic and policy constraints

The climate-resilience of pulses like cowpea make them an ideal crop for Sudan’s agricultural systems. Their ability to thrive in arid conditions and enrich the soil through nitrogen fixation is particularly beneficial for mixed cropping- or crop rotation systems and improves long-term soil health. However, the absence of targeted government support, such as subsidies, price guarantees, or access to affordable credit, severely limits its production and market potential. In contrast to wheat, which receives extensive policy backing, cowpeas and other pulses are neglected in national agricultural strategies (Abdelaziz et al, 2022).

Market

Pulses are traditionally used in rural areas as part of multi-cropping systems. Their consumption in urban areas is less common according to interviewed stakeholders. The market infrastructure for cowpeas is significantly underdeveloped, contributing to inefficiencies across the value chain. Inadequate storage facilities lead to substantial post-harvest losses, while limited transport networks hinder the distribution of cowpeas from production areas to urban markets. These challenges increase the cost of cowpea, making it less competitive compared to subsidized grains like wheat. Addressing these bottlenecks requires investments in storage solutions, such as silos and warehouses, and the development of efficient transport systems to link production hubs with consumer markets (Abdelaziz et al., 2022). Interviews revealed that it is often used alongside other crops like millet and groundnuts but lacks significant market demand compared to sorghum and millets.

3.5.5 Seasonality of local crops

Table 3 provides an overview of the planting and harvest periods for local wheat, sorghum, and millet in Sudan, along with observations on their availability and specific regional distribution:

- Wheat is cultivated in North Sudan in the cooler winter months (planted November-December) and then harvested between February and March.
- Sorghum is planted during the rainy season, which starts in June and lasts until July. Sorghum is planted all over Sudan. But particularly in the eastern states of Kassala, Gedaref, and Sennar, where

rain-fed agriculture dominates. Harvesting begins in October and can extend through December, depending on the variety of sorghum and local climatic conditions.

- Millets: Primarily grown in the western region of Sudan, millet is planted between mid-June and mid-July. Harvesting occurs from early September to mid-November. The growing period for millet varies depending on the variety, ranging from 70 days to as long as four months from planting. Like wheat and sorghum, millet is widely available.
- Cowpea: Rainfed areas (Kordofan, Darfur, Blue Nile, White Nile, and Gedaref) dominate cowpea cultivation, relying on seasonal rainfall. Limited irrigated production occurs in Gezira, Rahad, New Halfa, River Nile, and Northern State, but irrigation of cow pea is not common as limited water resources are typically allocated to higher-value crops. Additionally, cowpea is cultivated in dry season areas along the Nile and seasonal water basins, where residual soil moisture supports growth after the main cropping season.

Table 3 Availability of raw materials (source expert interviews)

	Local wheat	Sorghum	Millet	Cowpea
Region	North	East and across Sudan	West	North, West and East
Planting (month)	November and December	first of June to mid of July	Mid-June to mid-July	Rainfed: June–July Irrigated: November–December Dry Season: February–March
Harvest (month)	February and March	October and November	from early September to Mid-November	Rainfed: September–October Irrigated: February–March Dry Season: April–May
Observation		Typically sorghum takes 3.5 month from planting to harvest	Depending on variety, from 70 days to 4 months from planting	

3.6 Cost of local crops

3.6.1 Prices of (imported) wheat, sorghum, millet and pulses

In 2024, locally produced wheat prices were approximately 400% higher than in 2021. The conflict significantly disrupted wheat supplies. Prices of wheat more than doubled in monitored markets, with the Table 3 showing a steady rise to nearly SDG 1,000 by late 2023. In 2024, wheat prices spiked further, driven by ongoing conflicts, import challenges, and currency depreciation. The market data highlights this sharp increase, with prices surpassing SDG 1,600 by mid-2024.

Table 4 shows the price of imported wheat and highlights the impact of Sudan's deteriorating currency exchange rates on the cost of importing wheat. Although the international price of imported wheat has remained fairly stable at 350 USD per tonne from 2021 to 2024, the price in Sudanese pounds has escalated significantly due to the depreciation of the local currency. Despite this, imported wheat remains cheaper than locally produced wheat, highlighting the competitive disadvantage of Sudan's domestic wheat sector. A key factor in the dominance of imported wheat is its profitability for only a few large milling companies. Several elements contribute to this, including the past cost structure heavily influenced by subsidies.

Sudan's reliance on wheat imports worsens the issue, as local wheat production cannot satisfy national demand. Since wheat is priced in USD on the international market, Sudanese importers must exchange large sums of SDG for USD to purchase wheat. As the local currency lost value, the cost of SDG increased rapidly, translating directly into higher market prices for wheat and wheat-based products like bread. This depreciation has made imported goods, including wheat, exceedingly expensive for Sudanese consumers.

Despite the official exchange rate of the SDG to the USD being set, an informal parallel currency exchange rate more accurately reflects reality and has been used for our calculations[1].

Table 4 Price of imported wheat

	Market	Date	Weekly High Price in USD / t	Exchange rate USD to SDG	Price in SDG / kg
Imported wheat	International	Dec 2024	350	2,600	910
		Oct 2024	350	1,700	595
		Oct 2021	350	450	157

By March 2021, the average retail price of sorghum had reached SDG 98.21/kg, a slight increase of 0.90% compared to the previous month and 181% higher than in March 2020. Prices continued to rise throughout 2021 and into 2022, with the national average retail price climbing to 252 SDG/kg by April 2022, driven by reduced market supplies following a below-average harvest and increased demand during Ramadan (FEWS NET).

Since the outbreak of the conflict, sorghum prices in Sudan more than doubled due to reduced domestic availability, inflated production costs, and disrupted food marketing activities. The graph from the Ad Damazin market shows a steady increase from below SDG 300 in early 2023 to over SDG 1,000 by the end of the year. In 2024, the situation worsened as prices reached six times their pre-conflict levels in March 2023. By mid-2024, the graph indicates sorghum prices nearing SDG 1,000, reflecting severe constraints.

Millet prices followed a similar upward trend. By 2023, the conflict caused millet prices to more than double, as production and distribution were severely disrupted. The graph illustrates a steep rise from around SDG 600 in early 2023 to over SDG 1,200 by the end of the year. In 2024, prices continued to climb, with millet nearing SDG 1,500 by mid-year, reflecting the ongoing challenges in the millet sector.

Prices for pulses, in particular cowpea, are difficult to obtain since the price is not monitored in the market monitoring reports. The current consumer prices range from 5,000-6,000 SDG/kg in Port Sudan local market for cowpea. In the remainder of the report, we focus mainly on a general pulses price available for pigeon and chick peas and as a proxy for the cowpea price.

[1] https://dataviz.vam.wfp.org/eastern-africa/sudan/economic/exchange-rates

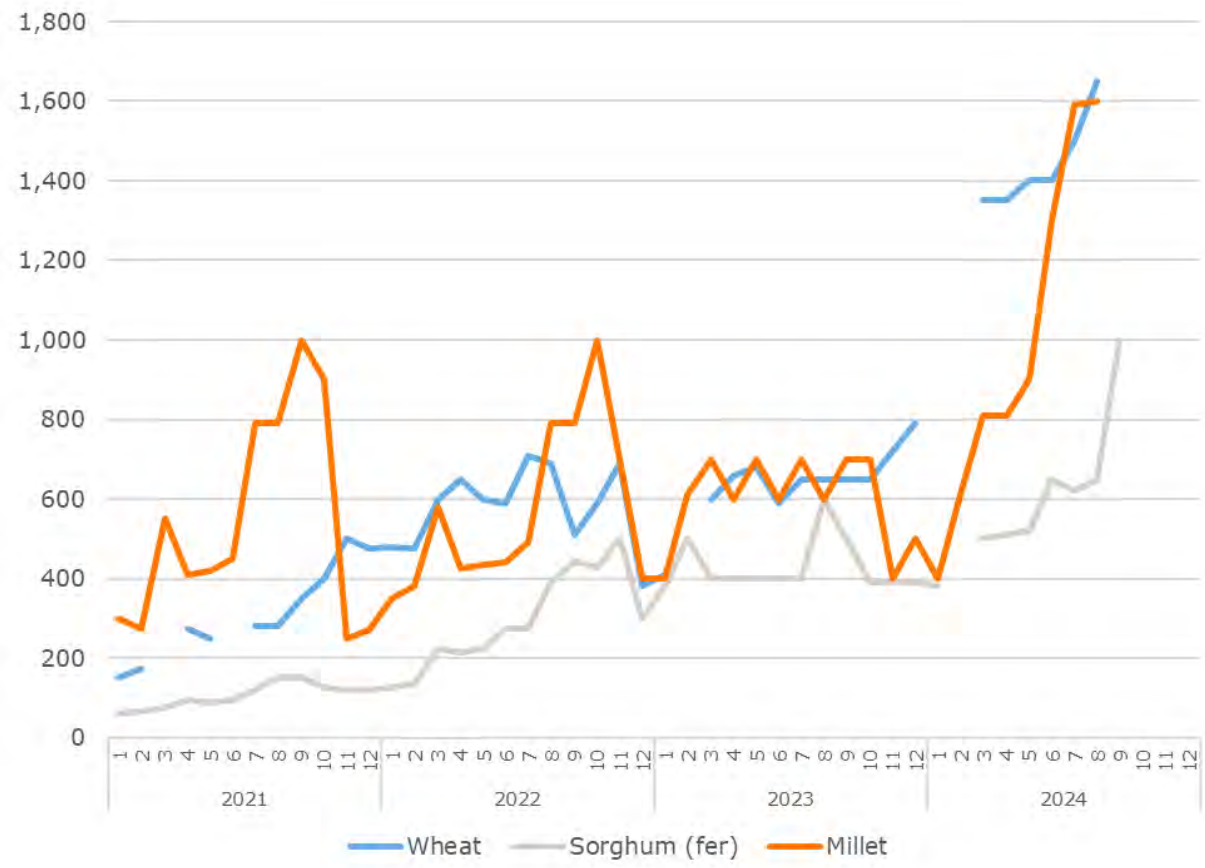

Figure 7 Monthly prices in SDG per kg raw material on Ad Damazin market (Source FEWS NET)

3.6.2 Seasonal and regional price effects

Prices of wheat, sorghum, millet and cowpea typically decrease during harvest periods (November to January). However, in recent years, high production costs, delayed harvests, and economic challenges have disrupted these trends, leading to price increases even during harvest periods.

The figure below provides insight into the average prices of raw materials across various states of Sudan, based on data availability. Wheat flour is the most expensive, with Central Darfur showing the highest price, exceeding 3,000 SDG per kilogram. Sorghum prices are generally lower than wheat flour but vary across regions, while millet prices fall between sorghum and wheat flour in most areas. East Darfur and South Kordofan have relatively higher prices for both sorghum and millet compared to other regions. Gedaref and South Darfur have comparable wheat flour prices, though still lower than those in Central Darfur.

Figure 8 highlights that wheat flour is more expensive compared to sorghum and millet. The regional differences in pricing reflect variations in production, availability, and logistical challenges affecting market dynamics.

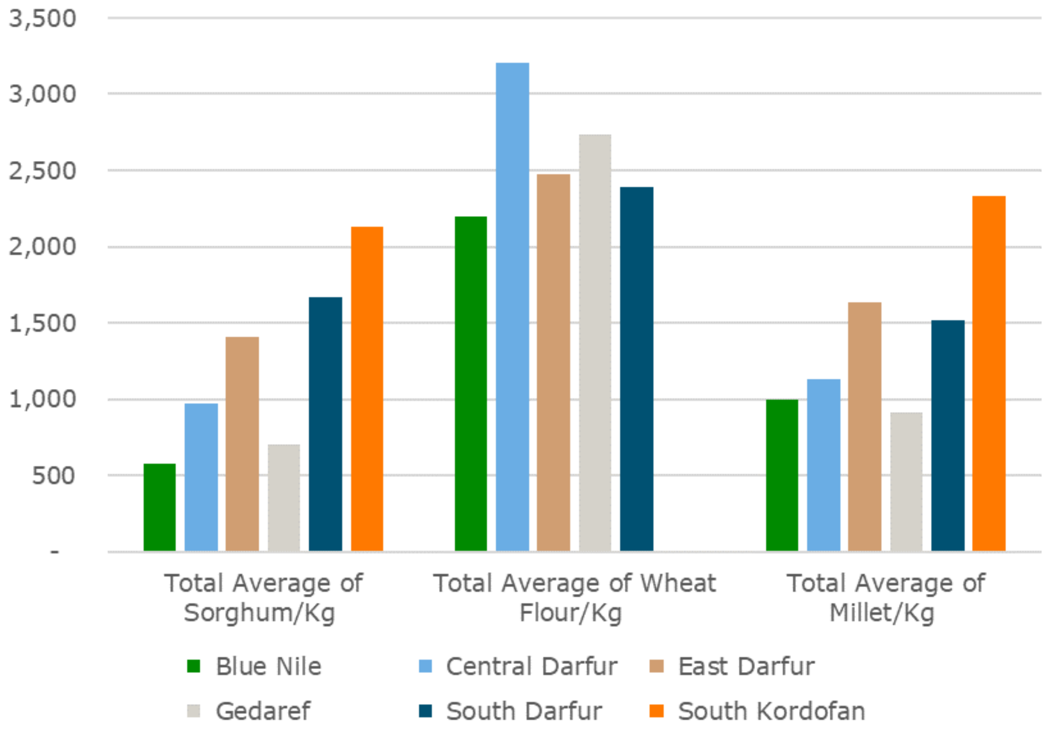

Figure 8 Average prices in SDG per kg raw material per State April to November 2024 (Source ZOA)

3.6.3 Conclusion

Raw material retail prices of local wheat, sorghum and millet are very volatile. As shown in Figure 8, the price of wheat, millet and sorghum has increased, making locally sourced ingredients much costlier than before. However, wheat and millet prices have risen the most, emphasizing the challenge of affordability in Sudanese markets. Having sorghum as a primary ingredient in the recipe is, therefore, an important opportunity to mitigate cost increases.

3.7 Sudanese milling and baking industry: capacities and value addition

3.7.1 Capacities

Demand for wheat has grown rapidly in the last 15-20 years, mainly driven by population growth, urbanization and changing consumer preferences for bread and other wheat products. Khartoum is the largest centre for wheat consumption, but even rural farm households consume wheat-based food, often selling sorghum and millet to buy wheat (Abdelaziz et al., 2022).

As such Sudan's milling and baking industry primarily relies on wheat, processed in large urban milling companies and distributed to bakeries across the country. The capacity to incorporate local crops like sorghum into the baking sector is limited by both infrastructure and consumer preferences. Sudan's baking industry comprises two main types of bakeries: those that use subsidized wheat flour for standard bread and mechanized bakeries that produce a variety of baked goods using commercial, higher-quality wheat flour.

Most milling facilities are designed for wheat, which presents a bottleneck for local crop processing. Sorghum milling, for example, is limited to smaller, decentralized mills, and lacks the quality control systems present in larger wheat-processing facilities.

Developing capacity for milling alternative grains like sorghum and millet would require infrastructure upgrades and potential incentives for millers and bakers to incorporate these crops into their products.

The ongoing conflict has also had a severe impact on Sudan's milling industry. Interviewed stakeholders indicate that only 20% of milling capacity is operational, with many millers unable to continue due to lack of electricity. Bakeries are now heavily reliant on generators, and charcoal has replaced gas due to fuel shortages. Most wheat is now imported in the form of milled flour rather than grain, with Turkey emerging as a major supplier. Companies, such as Sayga (DAL Foods), have relocated parts of their milling operations to Egypt, allowing them to continue serving the Sudanese market with processed wheat flour.

3.7.2 Value addition

An important drawback of Sudan's agricultural economy is the lack of industrial activities that add value to the country's exportable agricultural commodities. Most of these commodities, like gum Arabic, sesame, groundnuts, livestock and cotton, are mostly exported as raw materials, without any value addition. The same holds for local cereal and pulse crops that may be feasible for staple food production. Currently, these crops are mostly marketed as raw materials and consumed unprocessed (pulses) or processed only at household level. The milling of the local cereals is often performed in small batches at small chakki mills as a service. Processing crops into food ingredients and food production provide an opportunity value addition and economic activities and hence provide work and employment in Sudan.

3.8 Breads of Sudan

Sudan's bread culture is deeply woven into the fabric of daily life, and is reflecting the country's rich history, its diverse ethnic backgrounds, with an unique combination of African, Arabic and Mediterranean traditions. Bread is so entwined with the Sudanese way of life that it is usually called "aish", Arabic for "life". Aish is also a name given to sorghum, the most common produced grain and main staple in Sudan, that has been sustaining life for millennia, resulting in age-old bread making traditions that produce breads unique to Sudan.

Bread plays an important social role in daily diet and eating culture, and no Sudanese meal can be enjoyed without it. Sudanese are often used to eat a wide variety of foods through commonly practised hand feeding. The meals are eaten around a large, communal tray on which various meat, vegetable, salad, and sauce dishes are placed. These are eaten with the right hand, using the bread as a utensil for the food. In particular a variety of flatbreads and stiff porridges are the two main categories of traditional breads, and still are. They are served with stews in particular the ground vegetable and meat-based sauce "mullah", creating a nutritious and filling meal.

These culinary traditions of Sudan are still the standard way of eating, both in the rural and urban areas of Sudan, but do differ as well. In rural areas, a diversity of traditional breads made from local grown sorghum, millets and wheat is prepared, often produced at household level. In (semi)urban areas, wheat-based breads such as baladi (thick flatbreads) and aish (soft baguette-shaped breads), produced by formal bakeries are the most popular staples, reflecting the colonial influences and globalisation.

The diversity of breads and other cereal-based staple foods in Sudan varies not only on the level of urbanisation, but also on the different regions of the country, as the food culture is strongly intertwined with the local agro-produce, which is in its turn depending on the different agro-ecological zones of Sudan. Millet is mainly produced and consumed in the West of Sudan to produce aceda and other porridge-type products. Local wheat is mainly produced and consumed in the North of Sudan, in particular for making ghurassa, a thick wholegrain flat-bread. Although sorghum is produced and consumed throughout the country, faterita (red sorghum) is mainly produced and consumed (preferred) in Gezira. White Sorghum is produced and consumed across the country, and mainly in the East. Among white sorghum varieties, dabar is the most premium, tabat is a little less expensive, but also many other local varieties are used and valued by local people.

The different bread type staple products are traditionally made from specific local cereal sources: wheat, sorghum or millets. They can be classified according to different preparation techniques or product characteristics, but the foremost variation is in the water to flour ratio used in preparation. In this way dough-based products can be differentiated from thick batters and thin batters (see Figure 9). In combination with different product shaping (shape, thickness) and baking technique (cooking, grilling, oven-baking) also a wide variation in final moisture contents of the breads is obtained. The final products vary from liquid porridges like medida to semi-solid breads like baladi. In preparation different fermentation techniques may be used: non-leavened, yeast, or lactic acid bacteria. And different pH: neutral, acidic (fermentation) or alkaline (soda). Altogether, a wide variation in textures, tastes and flavour characteristics can be obtained.

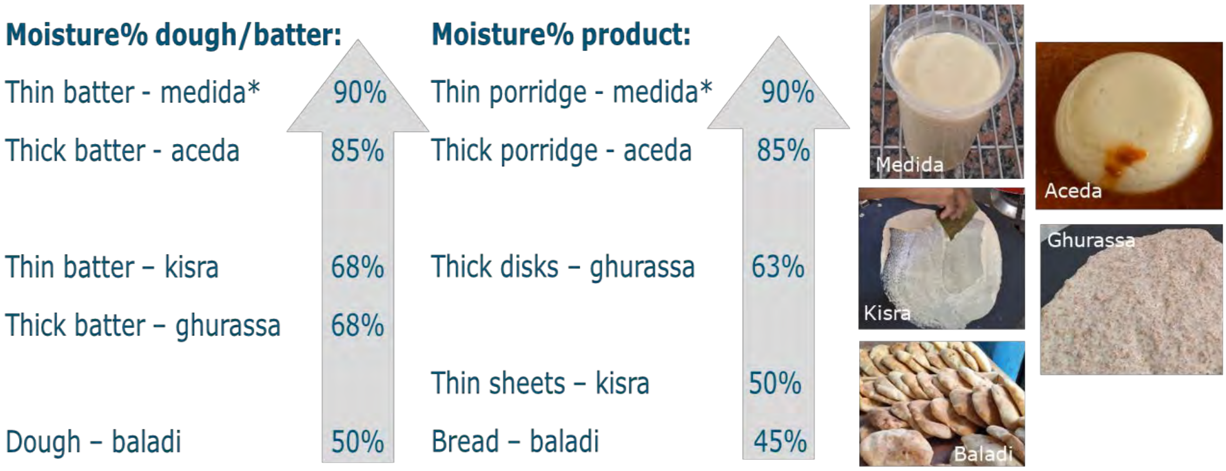

Figure 9 *Classification of Sudanese bread types according to their moisture content, based on Dirar (1993) and own calculations. *for medida the solutes sugar and salt are included in the moisture content (dissolved).*

Where the traditional staple food products based on local cereals are home- or fresh-cooked, they also have a relative short shelf-life. Typically, they are consumed within hours or at least the same day. Preparation of these products at household level is time-consuming and bakeries offering ready-to-eat wheat breads offer convenience. The traditional products based on sorghum, millet and local wholemeal wheat have specific flavour attributes which are highly preferred as an acquired taste. However, the shift towards refined wheat bread consumption is making these taste preferences to change in time, making it over time harder to drive consumer's back to appreciate local crop flavours. Consumer preference for wheat-based products in urban areas limits the market potential for sorghum, millets and pulses. Increased availability of convenience products like breads based on local crops are considered as an attractive way to regain consumption of local crops. Awareness campaigns focused on their health benefits could reshape consumer attitudes, particularly among urban populations less familiar with these traditional crops (IFPRI, 2023; Abdelaziz et al., 2022).

Wheat breads produced by formal bakeries are exclusively made from imported, refined wheat flour. Interviewees informed us that in the past attempts were made in Sudan to replace part of the refined wheat flour by mixing in sorghum flour (composite flour approach). These interventions were made to reduce Sudan's dependency on imported wheat and also for cost reduction. However, these attempts failed. The main reasons were told to be the unpleasant texture of the breads caused by sorghum, making it crumbly and dry. In the Sudanese climate the staling of the bread is a major issue.

Local wheat is specifically milled into wholemeal flour for ghurassa, prepared at household level. Formal bakeries rely entirely on imported refined wheat flour. No local wheat flour is being used as, according to millers (wheat importers), the local wheat is not of the right quality (high falling number, dry, low gluten quality). The types of wheat breads currently produced by bakeries (aish, baladi) should have a soft texture, which is more challenging to obtain with the local wheat. Literature (e.g. Makawi, 2013) confirms lower end-use quality of local Sudanese wheat, but demonstrates the potential of certain cultivars for bread baking as well. However, it should be noted that the amount of local wheat produced is Sudan is also a limiting factor.

3.9 Nutritional value of imported wheat and local crops

The traditional local cereals consumed in Sudan are sorghum, millet and wheat as wholegrain flours. These flours are very nutrient-dense, offering essential vitamins, minerals, and dietary fibre, which are lacking in refined wheat flour. As gluten-free grains, sorghum and millet provide dietary diversity for people with gluten intolerance or celiac disease. Sorghum is high in important minerals like iron and zinc, and rich in protein, lipids and fibres, making it a healthier alternative to refined wheat for those seeking added nutritional benefits, while millet, with its significant fibre and mineral content, enhances the nutritional profile of grain-based diets (Thomas and El Gizouli, 2020). However, due to the shift from these traditional staples towards consumption of refined wheat bread, wheat became the second largest source of calories in Sudan (530 calories/person/day), accounting for 20.6% of the estimated 2,576 total calories consumed daily (Abay et al., 2022).

Millets and pulses are nutritional powerhouses, providing high levels of protein, fibre, iron, calcium, and essential amino acids, making them valuable for diets that lack diverse nutrition sources. Pulses, in particular, are a primary source of plant-based protein, essential for both human health and food security in regions where meat is costly or scarce. The nutritional profile of these crops positions them as excellent dietary complements to wheat.

The nutritional value of local crops is compared to the nutritional value of wheat flour (refined and wholegrain) and maize in Table 5. To be most relevant for the nutritional contribution in bread-type staple foods, we present here the nutritional values of the flours as used for bread baking. For more detailed information on the nutritional aspects of the food crops and their flours, we refer to Noort et al (2022).

Table 5 Nutritional value of local crops in comparison to refined wheat flour, data from Noort et al (2022). Colours are added to indicate relative high (green) medium (orange) or low (red) contributions.

Nutrient	Unit/ 100 g	Refined wheat flour	Wholegrain wheat flour	Degermed maize flour	Wholegrain sorghum flour	Wholegrain millets flour	Sweet potato flour	Cowpeas whole
Water	g	13.4	13.1	12.0	12.4	12.0	12.0	12.0
Energy	kJ	1510	1368	1512	1377	1396	1390	1406
Carbohydrates	g	72.5	71.2	78.0	73.1*	75.0	77.9	40.7*
Sugars	g	0.31	0.41	0	2.53	2.60	16.19	6.90
Proteins	g	11.98	12.61	8.00	10.2*	8.50	6.08	23.9*
Lysine	g	0.231	0.335	No data	0.229	0.257	0.255	1.591
Lipids	g	1.66	2.1-3.8	2.00	3.46	1.40	0.19	1.26
Dietary fibre	g	2.40	12.2	2.00	10.5*	15.2	11.61	20.6*
Folate, total	µg	33	38	No data	20	No data	43	633
Vitamin A	µg	0	0	0	0	No data	2420–3420	3
Calcium	mg	15	29	0	13	343	116	110
Iron	mg	0.90	3.19	0	3.36	8.70	2.36	8.27
Zinc	mg	0.85	No data	No data	1.67	2.00	1.16	3.37

* measured data from Nikinmaa et al (2022).

When comparing the nutritional value of the flours inn Table 5, the nutritional value of refined wheat flour is clearly lower compared to wholegrain flours. Local wholegrain sorghum and millet flours have a high nutritional value compared to refined wheat flour, and the current trend shifting away from these local cereal crops is nutritionally undesirable. Mixing wholegrain sorghum or millet flour with portions of local pulse flours such as cowpea offers a substantial further nutritional enhancement, particular in protein and lysin content and the important micronutrients folate, calcium, iron and zinc. Including some orange fleshed sweet potato flour is of particular interest to enhance vitamin A content.

3.10 Selection of local crops of Sudan with potential relevance for bread products

From the long-list of available crops in Sudan (in section 3.2) we selected the crops that are most suitable for this project based on their:

1) Climate-resilience in Sudan: heat and drought tolerance (section 3.3);
2) Expected suitability for bread production: ability to mill into a flour and functionality for bread making. This assessment was largely based on WUR background knowledge and experience (Noort & Renzetti, 2023);
3) Costs and opportunity for value-addition: affordability compared to wheat flour (section 3.6), opportunities for processing and value addition and not yet used in high-value applications or export markets;
4) Nutritional value: similar or preferably enhanced compared to the refined wheat flour currently used (section 3.9).

From the cereals, sorghum and millets were selected. Local wheat and maize are not well climate-resilient. Sorghum is of high interest due to wide production across Sudan, their nutritional value and relative low cost. Sorghum is the most affordable crop. Millet has a higher nutritional value, but also a higher cost.

Many pulses of Sudan are of interest to be used: cowpeas, chickpeas, pigeon peas, broad beans (fava) and lentils. Cowpea and pigeon peas are of specific interest as they are widely produced and available and are produced as subsistence crops. As they are not processed yet, they offer specific opportunity for added-value. Chickpeas and faba beans are slightly more expensive and already processed into products like humus and falafel. For practical reasons, we selected cowpea flour, as it is available for experimental work. However, the other pulses can be used as well, and functional properties are considered to be quite similar.

From the oilseed legumes: sesame (*simsim*) and groundnuts (peanuts) were not selected as they already have a high value as cash crop. Soya beans are not widely produced and their available is limited.

From the roots and tubers: (orange flesh) sweet potato was selected based on their climate-resilience, availability, specific nutritional value (vitamin A) and potential to be increased in production in Sudan.

4 Demonstration of technical viability

The objective of this activities were to demonstrate the potential of selected local crops to replace refined wheat flour in some Sudanese bread type products. For this purpose, co-development work was performed by WUR and DAL foods, in the test-baking facility of Five Star Flour Mill, in Suez, Egypt, from 12-14 November 2024. This work had an exploratory nature: experiments are performed based on joint experiences, no experimental design was used, and capturing results was limited to subjective and qualitative assessments of quality, taste and texture. In this chapter a summary of the experimental work is given, for more detailed procedures, recipes and results, see Annex 4.

4.1 Materials

Sourcing of local crop materials followed the pre-selection of local crops that was made to replace imported wheat based on section 3.10.

Three Sudanese sorghum types and millets were sourced by DAL foods, milled as wholemeal flours:
- Sorghum Dabar (white, premium) milled in Sudan, extraction 96.5%
- Sorghum Tabat (white) from Sudan, milled in Egypt, wholemeal extraction unknown
- Sorghum Faterita (red) from Sudan, milled in Sudan, extraction 96%
- Millets from Sudan, milled in Sudan, extraction 97%

Several Climate-Resilient flours were sourced by WUR. These flours are not from Sudan, but considered as representative to be sourced from Sudan in the future, except for psyllium which mainly comes from India.
- Sorghum flour, wholegrain milled, (red colour), South-Africa, FT2022-128
- Cowpea flour wholegrain milled, cultivar Glenda (red colour), South-Africa, FT2019-269
- Cassava starch, native, FT2024-339
- Psyllium fibre (husk), commercial sample, Trouw Ingredients, the Netherlands, FT 2024-196
- Sweet potato flour, Commercial sample, Curad, Uganda, FT2022-221.

As reference imported refined wheat flour (Sayga) was used. This is the standard improved wheat flour as supplied to formal bakeries in Sudan by Sayga.

Commercial wholemeal wheat flour as used for ghurassa was obtained from the Egyptian market, Dobella, Al Masreq. The quality and fineness of this Egyptian flour was judged to be not as good as the ghurassa flour supplied by Sayga on the Sudanese market, it was more coarse. All other ingredients like yeast, sugar, salt, vegetable oil were used as available in the test-bakery and tap-water was used.

4.2 Ajin – sorghum ferment

Traditional breads and cereal products in the Sudan are often fermented by addition of Ajin. Ajin is a sorghum sourdough ferment, prepared by spontaneous fermentation, back-slopping or more controlled by using starting cultures. It is characterised by acid production with limited CO_2 production.
Ajin is based on 20% sorghum flour and 80% water, fermented overnight to achieve a batter of pH=3.5-4.0. The quality and safety of the ferment is judged by smelling and tasting the flavours (pleasant acidity without off-flavours). In Sudan, sun-dried ajin is produced and sold as ajin powder starter-culture by informal businesses. In our case we used back-slopping based on an existing ajin provided by dr. Hannaa El Sadig. The pH of the refreshed ajin was 3.7 when used.

4.3 Aceda and Medida

Aceda (aceeda/aseeda) is a thick porridge, consumed as a traditional staple for breakfast, lunch and dinner. It is never consumed in isolation, but with mullah (sauce with okra), soup or (sour)milk (Dirar, 1993). Aceda is traditionally made from pure sorghum (or millet), but nowadays aceda flours on the (formal) market usually contain 20-30% refined wheat flour. Wheat is included primarily for the light colour, but also gives more cohesion. In the South sometimes white maize flour is added for the colour. Medida is a sweet, thin, drinkable porridge, based on millet, with a silky-smooth texture.

Since Aceda and Medida are mainly based on local climate-resilient crops already, the purpose of the preparation of these products was to learn about the cooking techniques and the texture, taste and flavour attributes of these traditional foods. The details of the recipes and experiments are shown in Annex 4. An interesting learning from preparing these products, was the specific flavour and colour attributes induced by soda addition to millet based aceda and medida. These specific alkaline properties are highly preferred by Sudanese consumers and hence, we also tested the addition of soda in millet based bread recipes.

4.4 Kisra

Kisra is a relative thin batter-based flatbread, fermented by ajin and baked into paper-thin flexible sheets of bread as shown in Figure 10. It is mostly produced fresh, consumed within hours, as it deteriorates very quickly, mainly due to dehydration. Kisra is mostly produced at household level, some women bake it at the street (informal sector). Few initiatives were taken to industrialize and sell packed via supermarkets under the Amreen brand of DAL foods. Traditionally, kisra is made from 100% sorghum, but nowadays, common flour for kisra is a 70%sorghum-30%wheat mixture, as wheat improves the texture (improves cohesiveness). Since kisra is mainly made from local crops, we only performed limited experiments, in which we tested the use of cowpea (pulse) flour and psyllium in replacement of the imported wheat. Pulses are of interest for nutritional improvement, and together with psyllium expected to provide cohesiveness to the sorghum based kisra. As a reference, kisra was made from the commonly used mixture of 70% sorghum – 30% imported refined wheat flour. This was compared with recipes based on sorghum, cowpea, and some psyllium at 2 inclusion levels. The details of all recipes and experiments are shown in Annex 4.

Figure 10 Kisra process, the batter is obtained by mixing sorghum flour with Ajin and water in a vessel using a mufraka and thin sheets of bread are baked on a griddle.

The alternative recipe of 94% sorghum, 5% cowpea and 1% psyllium provided a very nice kisra without wheat. The flavour and texture were judged as very good. No beany flavour of the cowpea was noted. This may be a result of the ajin fermentation. In the appearance, small specks of cowpea hull were visible and were disliked by the Sudanese co-workers. Hence, white pulse varieties may be more suitable, or dehulled pulse flour could be used, although the latter would reduce the nutritional improvement somewhat. The nutritional value is improved, although the relative increase is limited since sorghum was already the main component.

4.5 Ghurassa

Ghurassa is a thick batter-based flatbread, baked into thick disks. It is mostly produced fresh, at household level, not in formal bakeries. Ghurassa is the traditional staple from the North, made from local wheat, not from imported wheat. Wholegrain wheat flour for ghurassa is produced at chakki (stone) mills, to produce relative finely ground meal, with high water absorption to contribute to the thick batter (see Figure 11). Nowadays, also (partly) refined wheat flour may be included.

Since ghurassa is mainly made from local wheat, in this product it may be less relevant to replace the wheat by sorghum. Therefore, we tested the inclusion of cowpea (legumes) to the wholegrain wheat ghurassa for nutritional improvement. However, since sorghum cultivation is more climate-resilient and more affordability compared to wheat, we also tried to replace the wholegrain wheat by wholegrain sorghum in combination with cowpea and psyllium. The details of all recipes and experiments are shown in Annex 4.

Figure 11 Ghurassa process, the thick batter is spreaded by hand and slowly baked on a griddle.

The results of the baking tests indicate that wholegrain wheat with cowpea is a promising option to improve the nutritional value of ghurassa. It should be noted that wholegrain wheat ghurassa already has a nutritional composition, and the inclusion level of 10% cowpea is limited. However, lysin level substantially increased and micronutrients such as folate more than doubles. Cowpea provides a more aerated batter texture, a bit pronounced pulse-flavour, but overall a very nice product. The standard sorghum-cowpea-psyllium ratio used in the other baked products resulted in a too thick batter. The very high water retention, was not positive for ghurassa baking and makes it difficult to bake it well (remained undercooked). Using sorghum flour (88.7%) with cowpea (10%) and low amount of psyllium (1.3%) provided very promising results, with very pleasant taste and texture as judged by the Sudanese co-workers.

4.6 Baladi bread

Baladi (flat disks) and aish (finger bread, soft baguettes) are the two most common breads found in Sudan. These breads have a soft porous crumb structure and a thin flexible crust. They are entirely produced based on imported refined wheat flour, as high-quality gluten contributes to dough properties and pore structure. They are mostly produced fresh, consumed within day(s), although they can be kept well for several days when packed in plastic. Stale breads are sun-dried and crumbled into granules. Granules are a popular breakfast porridge in milk, comparable to breakfast cereals. Due to their growing (urban) popularity and dependency on imported wheat flour, baladi was selected as main objective to be made from local crops in this project. The details of all experiments are shown in Annex 4.

In previous research a basic recipe consisting of sorghum, cowpea, cassava and psyllium was developed in Uganda. Since cassava is not produced locally in Sudan, and in the absence of alternative cheap carbohydrate sources, we focused on sorghum and millet as the main local crop ingredients, combined with cowpea for nutritional improvement and psyllium for its functional properties based on the pre-developed ratios. Sweet potato is locally produced in Sudan, and was tested in a side-experiment. The basic recipe with sorghum or millet as main ingredients is shown in Table 6. The amount of water in the recipe was adjusted subjectively to reach equal dough consistency and avoid a sticky dough.

Table 6 Basic baladi recipe based on local crops.

Ingredients	Weight (g)
Sorghum/millet	100
Cowpea Flour (Glenda)	9.5
Psyllium fibre	8
Instant dry yeast	2
Salt	1
Sucrose	1
Vegetable oil	4
Water	125-150

With this ratio of ingredients, flexible and pliable dough was obtained, by just blending it with water. No kneading of the dough was needed, due to the absence of gluten. The dough properties are different from a wheat flour dough, in particular as the dough is less extendable and elastic. However, the dough can be shaped and rolled into thin sheets quite easily. For bakers this would require adjustments of their practices, with some advantages and disadvantages, but considered as technically feasible.

The sorghum and millet based baldi bread texture was best developed when the dough sheet had a medium thickness of ~0.8-1 cm and baked on the floor of a high temperature oven (330°C), consistent with the traditional wheat based baladi process. In this way, a baking time of around 5 minutes was sufficient to obtain breads with a porous bread crumb and a flexible well coloured crust (Figure 12). Overall the crumb texture was more dense compared to wheat based baladi, but considered to be attractive and the distinct flavours of the main cereal flour types used (dabar, faterita, millets) were clearly perceived in the bread, while the flavour of the pulse flour was very neutral. These results show that attractive baladi type breads can be made based on local, wholegrain, climate-resilient crops like sorghum and millet flour to replace imported wheat flour, when using psyllium as a functional ingredient. Whole cowpea flour (as well as other pulse flours) can be included for nutritional improvements.

In one experiment ajin was included in a sorghum based baladi recipe, replacing some of the yeast. The dough with ajin was very supple, but clearly stiffer and less sticky, indicating a change in functionality. This may be attributed to a direct effect of the fermented sorghum in the ajin, or as an effect of lower pH on sorghum, cowpea and/or psyllium functionality. These observations are interesting for further research, in line with the findings of Ali et al (2024), who found that fermentation may functionalize sorghum flour. The sorghum bread with ajin seemed to have a denser crumb texture – in line with expectation that ajin gives limited CO_2 production. The inclusion of ajin had a very nice effect on crust colour (warm) and by pronouncing the sorghum flavour. The flavour was highly preferred by the Sudanese co-workers.

Inspired by the addition of soda for making millet aceda, soda was used in replacement of yeast in millet baladi. Due to the soda, the millet dough had an intense yellowish colour, was very pliable and non-sticky. The breads obtained the distinct alkaline-millet taste which is highly appreciated in Sudan. This result was considered as very promising for further development. The use of Ajin (or lactic acid fermentation in general) and soda (alkaline fermentation) hold particular promises for further developments of attractive and nutritional products. It shows that the developed products fit well in local food traditions, fermentation techniques and traditional taste and flavours of Sudan.

A very interesting result was that the sorghum and millet based doughs showed very nice pillowing/puffing effects when baked on the oven floor at high temperature (330°C). This property demonstrates good gas holding properties of the dough and is a very important property in the production of double-layer flatbreads such as pita breads also called Arabic or Lebanese bread. This capability has a very interesting potential for such products, but in current study we focussed more on baladi texture.

Figure 12 Baladi bread made from imported refined wheat flour (reference, top left) and the results of first experiments with local sorghum and millet flours without any optimisation (dabar top right, faterita bottom left and millet bottom right).

It was also possible to bake the sorghum- and millet-based doughs in thin disks on a hot plate/griddle, to provide very nice chapati-type flat breads. The texture of these breads was evaluated to be very nice, cohesive and rollable. Also the taste and flavour were liked, with distinct flavour characteristics of the sorghum and millet varieties used. The chapati-type product is not common in Sudan, but could be a very nice new snack, especially with honey according to the Sudanese co-workers.

Replacing 50% of the sorghum by sweet potato flour worked well. The water absorption decreased, but the dough was well pliable. The crust colour gets too dark during baking at 330°C, but at 230°C it worked well. Longer baking time was needed to complete the baking, but a very nice and open bread structure was obtained. The texture was very soft, also after a day stored. The sweet potato flour gives a very sweet taste, masking the sorghum flavour. At the level used, it was too sweet to be consumed with savoury dishes. The results are considered as promising for further optimisation and lower inclusion levels of 10-20% may work very well.

4.7 Nutritional value of breads from local crops

It is expected that shifting from the usual white wheat bread to the developed bread from wholegrain local crops can provide a substantial nutritional improvement. However, within the scope of this project it was not possible to determine the nutritional value of the breads. To illustrate the potential nutritional improvement, we calculated the nutritional value of the developed local flour mix and compared it with refined wheat flour, as shown in Table 7. It should be noted that the higher water absorption of the wholegrain local crop mixture will somewhat dilute the nutritional value of the flours.

Refined wheat flour is a good source of protein, although low in the essential amino acid lysine. The local crop mix is almost as high in protein, but improved in lysine content. Also the lipid content and in particular the level of dietary fibres is substantially higher in the local crop mix. In particular the macronutrient composition of the local crop mix is superior to that of refined wheat flour. The levels of folate, iron and zinc are substantially improved. To illustrate the size of this improvement, the relative increase in these micronutrients is also expressed in %RDI (Recommended Daily Intake). Since we don't have the RDI for Sudanese population, we used the RDI for 18+ females in the Netherlands. With 100g of flour consumed, about 1/4th of the daily requirement of folate, iron and zinc can be achieved, indicating that substantial nutritional improvements can be obtained.

Table 7 Nutritional value of refined wheat flour versus the flour mix of local crops (sorghum 85.4%; cowpea flour 8.1% and psyllium 6.8%) by calculation based on nutritional value of individual ingredients (Noort et al, 2022). The last column shows the change in micronutrient content per 100g flour(mix) expressed in %RDI (Recommended Daily Intake for 18+ females in the Netherlands). Colours are added to indicate relative high (green) medium (orange) or low (red) contributions.

Nutrient	**Unit/ 100 g**	**Wheat flour refined**	**Sorghum, cowpea, psyllium**	**%RDI/100g change**
Water	g	13.4	12,1	
Energy	kJ	1510	1343	
Carbohydrates	g	72.5	65.9	
Sugars	g	0.31	2.7	
Proteins	g	11.98	10.74	
Lysine	g	0.231	0.324	
Lipids	g	1.66	3.1	
Dietary fiber	g	2.40	16.6	
Folate, total	µg	33	68	11 → 23
Vitamin A	µg	0	0.2	
Calcium	mg	15	20	1.6 → 2.1
Iron	mg	0.90	3.5	6 → 22
Zinc	mg	0.85	1.7	12 → 24

5 Demonstration at Sudanese SME baker

To evaluate and collect feedback from some SME bakers, we identified some small Sudanese bakeries via google maps in Boulaq, Egypt, an area with large Sudanese low-income population. We visited the Sudanese bakery 'Zool Faron Al-Khair Al-Sarabi' ('Zool for Sudanese Bread'), see Figure 13 in Boulaq and performed a small demonstration experiment after consent of the owner. The bakery produces Sudanese baladi breads from refined wheat flour. They also produce Sudanese chickpea based falafel in front of their bakery, which are sold as such, or as filling of the baladi bread as a sandwich.

Figure 13 ***Sudanese SME bakery 'Zool Faron Al-Khair Al-Sarabi' in Boulaq, Egypt.***

The Sudanese baladi breads are made from rather soft dough (~70% water) mixed with a dough mixer, divided, rounded, flattened into ~1cm discs and placed on wooden stacking plates to ferment at ambient temperature (see Figure 14). The baking is performed in a direct flame heated, gas fired belt-oven. The temperature seemed to fluctuate a lot as they tried to empty the gas tank. Hence, also the baladis varied a lot in colour and needed to be pushed back manually into the oven many times. Also some breads had to be discarded as they went black (not shown in photos).

Figure 14 Sudanese baladi bread process; dough mixer and fermentation crates (left) dough pieces entering the belt oven (top right) and baked products coming out (bottom right)

A complete local crop flour mix, as shown in Table 8, was prepared the week before the experiment, anticipating that there are no weighing scales and utensils available in the bakery. Pictures of the process and product are shown in Figure 15. The flour mix was manually mixed in ~1min. with about 250mL of water, and yielded a quite soft and pliable dough. The dough was divided in 4 more or less equal parts (~120g) and rounded to rest about 20 min. A little bit wheat flour was used as dusting. The dough balls were easily flattened to discs of about 1cm thickness and ~15cm diameter. After another 20 min resting, the dough pieces were placed on the oven belt and baked for about 5-7 min (pushed back at the end of the oven to receive the right colour, like also done for the normal baladi). The dough did pillow/puff somewhat and provided nice and soft baladi-type breads. Obviously, the colour is darker due to the wholegrain flours used. Also the colour of the crust was quite dark. The crust of the product had a pleasant bite. Inside, the breads had a porous crumb structure and a large cavity typical for baladi. The crumb was soft and a bit gummy (a little longer baking at a little lower temperature is advised). The taste was nice, wholemeal type taste, no beany or bitter tastes, bit low in salt.

The temperature of the oven was not ideal for this product (optimized for the wheat baladi) but still the baking result was quite good. Baking at a little lower temperature will probably further improve the results.

Table 8 Flour mix formulation and its use to prepare dough in the SME bakery

Flour mix	Bakers%	Weight (g)
Sorghum flour TABAT	100	200
Cowpea Flour (Glenda)	9.5	19
Salt	1	2
Instant dry yeast	4*	8*
Psyllium flour	8	16
Total dry ingredients		245
Water added		~ 250 mL

* High amount of dry yeast included, since the package had been open for some days, and yeast activity was already reduced. The yeast also needed to be mixed into the flour mix for some days.

Figure 15 Sorghum based baladi bread test: from left to right and top to bottom: rounded dough balls, 2 dough pieces entering the belt oven, baked products leaving the oven, the sorghum breads having similar characteristics as the wheat based baladi breads, but with a darker colour.

Although the sorghum based test breads were not optimized, we wanted to get some feedback of the bakers on their assessment of the acceptability of these breads. The master baker Samuel assessed the breads as quite good, although he missed a bit of salt. The owner of the bakery was very positive, and thinks the bread would be acceptable for consumers. The Ethiopian co-workers tasted the breads and thought they were okay. The Egyptian co-worker was very negative about the bread, he didn't understand the idea of making a dark-coloured bread. We also discussed the bread with the falafel baker, who was quite positive. He filled the sorghum baladi with his falafel (Figure 16), as this is a typical way of eating it as a snack/food on the go, and liked eating it.

Figure 16 Sorghum based baladi bread filled with Sudanese falafel (left), tasting by baker (right)

We also took the breads to some other bakeries in the area. In the first bakery was a young man of ~18y old. He didn’t like the bread at all and preferred white wheat bread strongly. Visiting a Sudanese bakery some streets ahead (Figure 17b), the owner liked the bread a lot, also the flavour, and he wanted to keep the bread to eat it with his tea. Lastly, we visited a Sudanese supermarket selling also Sudanese and Ethiopian breads (Figure 17c). The owners were quite positive about the sorghum based breads and assessed it as acceptable for consumers.

Figure 17 Asking the feedback of Sudanese bakers on the sorghum based baladi: owner of Sudanese bakery (A), another Sudanese bakery some streets ahead (B), owners of a Sudanese supermarket selling also Sudanese and Ethiopian breads (C).

The evaluation of the sorghum based baladi (not optimized) by Sudanese bakers provided mixed responses. Some very positive, but some also negative. We anticipate that the differences are mainly dependent on openness to try non-white / non-wheat products, and level of exposure to sorghum/other grain consumption. However, it was not possible to question in this small evaluation.

6 Economic feasibility assessment of local crops for flour

6.1 Recipes

Based on the experimental work of baladi (Chapter 4) we selected one basic local crop mixture as an alternative for the imported refined wheat flour as used currently for bread production. Recipe A primarily uses wholegrain sorghum flour with a 98% extraction rate, making up 85.4% of the flour weight, along with wholegrain cowpea flour, also at 98% extraction, contributing 8.1%. Psyllium is included at 6.8% as an additional ingredient, used for its binding properties and also enhancing dietary fibre content. The water content in recipe A is 112% relative to the flour weight, reflecting the higher water absorption of these flours used compared to refined wheat. The advantage of high water absorption is that 1kg of flour will yield a higher product weight, i.e. the cost of use for producing a certain weight of product is lower.

In contrast, recipe B relies solely on refined wheat flour with a 76% extraction rate, which accounts for 100% of the flour weight. This dough is representative for the current practices at bakeries preparing wheat based staple breads like aish and baladi, based on refined, imported wheat flour. The water content in this recipe is 70% relative to the flour weight, as used in practise, and significantly lower than in recipe A.

For the cost price calculations for different flour recipes we only consider raw material costs. All other costs related to milling and packing are considered to be the same for the recipes. Also minor ingredients in bread formulations, like salt, yeast and oil etc, are considered to be constant and therefore excluded from the calculations. The table below compares two recipes, labelled as A and B, by listing their ingredients, quantities, and additional information. For this feasibility assessment we refer to prices before the conflict and to current prices in order to compare scenarios.

6.2 Cost for inputs

In Table 9 the different recipes for the improved flour are presented. Wheat, sorghum and pulses are the key raw materials. But also psyllium is a key input for recipe A.

Table 9 Recipes of local crop flour mix (A) and imported refined wheat flour (B).

Recipe	Ingredient	Quantity (baker's%*)	Dough yield (g dough/100g flour)
A	wholegrain sorghum (98% extraction)	85.4	
	wholegrain cowpea (98% extraction)	8.1	
	psyllium	6.8	
	water	112	212
B	refined wheat flour (76% extraction)	100	
	water	70	170

* Baker's% was used as this is usually applied in bakery recipes, where the sum of the flour used is considered as 100% and all other ingredients like water and minor ingredients are indicated as % of flour, and added on top of the flour.

We applied different methods to calculate economic estimates, using two approaches to determine the prices of sorghum and wheat, the results of the calculations are shown in Table 10.

Option One (Point-in-Time Prices):

- Sorghum: In October 2021, the price was 150 SDG per kg, while in October 2024, it increased to 1,000 SDG per kg.
- Wheat: In October 2021, the price was 350 SDG per kg, rising to 1,600 SDG per kg in October 2024.

Option Two (Annual Average Prices):

- Sorghum: The annual average price in 2021 was 90 SDG per kg, increasing to 512 SDG per kg in 2024.
- Wheat: The annual average price in 2021 was 314 SDG per kg, rising to 1,442 SDG per kg in 2024.

For pulses, we used a similar approach: The price in 2021 was 453 SDG per kg, increasing to 2,000 SDG per kg in 2024. The 2021 price was estimated based on the average price increase observed in other crops.

Determining the actual cost of psyllium is quite complex. We know that the import cost of high-quality psyllium (pharmaceutical grade) into the Netherlands is approximately $8 per kilogram. This figure has also been used as a (worst-case) benchmark for Uganda, recognizing that Uganda is a landlocked country just as Sudan (Noort and Renzetti, 2023). However, it is expected that we could work with a less pure variant of psyllium, which should allow for a significantly lower price. When examining wholesale prices, for instance, on platforms like Alibaba, bulk prices (with a minimum order of one metric ton) range between USD1.25 and USD2.50 per kilogram. For smaller orders, prices vary between $1.25 and $10 per kilogram. This suggests that sourcing psyllium at a much lower cost than the Netherlands benchmark is feasible, particularly if a less refined quality is acceptable for the intended use. However, also the depreciation of the SDG to the USD should be considered. Therefore, for psyllium, we took a price from 2021 of 2,250 SDG per kg. For 2024, we took the price of 8,500 SGD per kg. This reflects an average international market price of 5 USD per kg. For water, it was not valued in 2021, and it remains not valued in 2024.

Table 10 Price assumptions in SDG per kg for the calculations with different price assumptions

	2021 (October)	2024 (October)	2021 (year average)	2024 (year average)
Sorghum	150	1,000	90	580
Wheat	350	1,600	314	1,442
Pulses	453	2,000	453	2,000
Psyllium per kg	2,250	8,500	2,250	8,500
Water	Not valued	Not valued	Not valued	Not valued

To calculate the raw material cost price of different flour recipes, we used the ingredient prices per kg and use the given formulation percentages. We calculated the cost prices using actual price levels from 2021 and 2024 (with a price point taken in October), considering the steep increase in raw material costs. Based on this we calculate a cost price per kg for raw materials, shown in Table 11 and Table 12. The formulas used in this analysis help determine the total cost per kilogram for each recipe by considering the contribution of each ingredient based on its percentage composition and market price. The flour cost price was determined for the total cost per kilogram for each recipe by considering the contribution of each ingredient based on its percentage composition and market price. We also calculated the dough yield since a 50g bread piece has a certain value and requires less sorghum flour than wheat so this makes it more beneficial.

Cost price for recipe A (Sorghum + Pulses + Psyllium):

- 2021 price level: 279.7 SDG/kg to 318 SDG/kg
- 2024 price level: 1,252.4 SDG/kg to 1,594 SDG/kg

Table 11 Calculations with 2021 and 2024 price level recipe A

	Ingredient	Percentage in Recipe A (%)	2021 Price per kg (2021) (SDG)	Cost in Recipe A (2021) (SDG)	2024 Price per kg (2024) (SDG)	Cost in Recipe A (2024) (SDG)
Point in time calculations	Sorghum	85.4	150.0	128.1	1,000.0	854.0
	Cowpea	8.1	453.0	36.7	2,000.0	162.0
	Psyllium	6.8	2,250.0	153.0	8,500.0	578.0
	Raw material costs per kg			*317.8*		*1594.0*
	Raw material costs per kg dough			*150.0*		*753.0*
Years average calculations	Sorghum	85.4	105.4	90.0	600.0	512.4
	Cowpea	8.1	453.0	36.7	2,000.0	162.0
	Psyllium	6.8	2,250.0	153.0	8,500.0	578.0
	Raw material costs per kg			*279.7*		*1,252.4*
	Raw material costs per kg dough			*141.0*		*591.0*

Cost price for recipe B (Refined Wheat Flour only)

- 2021 price level: 313-350 SDG/kg
- 2024 price level: 1,442-1,600 SDG/kg

Table 12 Calculations with 2021 and 2024 price level recipe B

	Ingredient	Percentage in Recipe A (%)	Cost in Recipe B (2021) (SDG)	Cost in Recipe B (2024) (SDG)
Point in time calculations	Wheat	100	350	1,600
	Water			
	Raw material costs per kg		350	1,600
	Raw material costs per kg dough		206	941
Years average calculations	Wheat	100	313.5	1,442
	Water			
	Raw material costs per kg		313.5	1,442
	Raw material costs per kg dough		185	848

7 Conclusions and pathways for scaling

7.1 Conclusions

Leveraging local crops like sorghum and cowpea offers Sudan a pathway toward greater food independence, resilience, and nutritional diversity. However, realizing this potential will require substantial investments in agricultural modernization, infrastructure, and consumer awareness campaigns. Reducing Sudan's dependence on imported wheat will not only address food security concerns but also alleviate the economic strain of subsidy-driven wheat imports. For a sustainable food system, Sudan has to prioritize policies that level the playing field for local crops, support rural producers, and foster a diversified diet across both rural and urban populations.

The main objective of this study was to test the feasibility of this approach in Sudan, to provide opportunities for enhancing the use of local climate resilient Sudanese staple foods. Desk research and interviews were taken with various actors: private sector, NGOs, experts and other stakeholders. The second aim was to demonstrate the potential of selected wholegrain local crops to replace refined wheat flour in some Sudanese bread type products, like baladi, kisra, ghurassa and aceda. This was performed by an exploratory co-development activity with Sudanese private sector.

The results of this study show that nutritional and attractive Sudanese staples can be made based on local, wholegrain, climate-resilient crops. Wholegrain sorghum and millet flour can be used to replace imported wheat flour in Sudanese baladi bread, when using psyllium as a functional ingredient. Whole cowpea flour (as well as other pulse flours) can be included for further nutritional improvement, increasing the protein content, specifically lysine, as well as important micronutrients. Also other local crops, like sweet potato, may have potential to be included, but needs further research.

The economic feasibility is positive, since the local crop mix is lower in cost compared to local wheat flour as well as to imported wheat flour on the domestic market. However, these domestic prices are substantially higher compared to that of refined wheat flour on the international market, which will probably favour companies with access to international trade to keep importing and using wheat.

Leveraging local crops could make it a more attractive and viable supplier to the domestic market, reducing reliance on imported wheat. However, potential trade-offs must be considered. Since sorghum, millets and pulses have rather low market prices, promoting their production should not lead to the displacement of other, economically important crops. However, as these crops require low inputs, labour and are mainly cultivated in rain-fed areas land use seems not a main limitation. More importantly, there is still significant potential to increase current yields, by improved seeds, inputs and farming practices. For such investments, increased (domestic) demand for these crops is required.

Besides the technical and economic feasibility, the developed products fit well in local traditions of Sudanese foods, fermentation techniques and traditional taste and flavours of Sudan. Wholegrain flours of local climate resilient crops have the potential to strengthen the local food system resilience in Sudan and we currently discuss with stakeholders the possibilities for scaling this innovation in Sudan.

Since this study was exploratory, we recommend validating the findings before proceeding with implementation and scaling.

7.2 Barriers and pathways for scaling

7.2.1 Barriers

Our research demonstrates that attractive bread products can be produced using the proposed mix of ingredients. However, we identified the following barriers for adoption:

- Due to differences in dough and product properties, bakeries will need to make certain adjustments. Without strong cost incentives or clear consumer demand, local bakeries may have limited motivation to incorporate local crops into their bread production.
- In Sudan's urban areas, consumers are accustomed to white wheat bread with a mild, slightly sweet taste. Many perceive darker-coloured or differently flavoured bread as inferior, often associating it with lower-status food. To overcome this challenge, consumer awareness campaigns should highlight the nutritional and health benefits of bread made from local crops. If effectively communicated, these benefits could enhance consumer interest and serve as a compelling selling point.
- While the feasibility of using local crops for bread production appears promising, several barriers hinder large-scale adoption. These crops are predominantly cultivated in rainfed areas, on a small scale, with minimal or no input use, leading to low productivity. Additionally, their supply chains are informal and underdeveloped, resulting in inconsistent quality and availability. This lack of supply chain reliability limits large-scale utilization and should be considered for large scales pilots.
- Furthermore, local crops remain relatively expensive compared to imported wheat, making them less economically attractive for millers with access to international markets. The need to blend these crops with psyllium further complicates procurement, milling, and blending processes compared to single-grain wheat milling.

To address these barriers and confirm the viability of scaling up, validation activities should engage key stakeholders—farmers, millers, bakeries, and consumers—to assess incentives and ownership. New or ongoing development programmes in Sudan or a public-private partnership could be instrumental in organizing a pilot study to commercially validate the approach, ensuring practical feasibility before broader implementation. Such a pilot study should include a market survey to ensure consumer acceptance. Furthermore, a follow-up project should be planned and implemented in collaboration with the national mandated entities, namely the National Food Research Centre and the Standard and Metric Authority of Sudan, as the authorizing and regulating institutions for formula approving and for policy scaling.

7.2.2 Pathways for scaling

Implementation and scaling can be envisioned through several pathways, depending on the type of stakeholders involved and the social-economic aims. Some options and their advantages (✓) and disadvantages (-) could be for instance:

- Uptake by a large milling industry:
    - ✓ Have technology capacities
    - ✓ Have access to financing
    - ✓ Have existing distribution network to bakers
    - \- Economic advantages to incentivize to adopt are questionable
- Uptake by small millers in rural areas:
    - ✓ Business model fits with informal supply chains and milling technology: chakki mill is sufficient.
    - ✓ Small-holders and vulnerable populations can directly benefit from economic activities and nutritional products
    - ✓ Rural consumers may be more willing to adopt to traditional colour and taste aspects?
    - \- Psyllium supply may be complex: small millers don't have bakery supply network nor organizational skills
    - \- Limited access to financing etc
    - \- Coordination is missing in the local raw materials value chains and is needed to be more competitive against imported wheat
- Uptake by targeted Public-Private-Partnership similar to Africa Improved Foods in Rwanda:
    - ✓ Social enterprise, inclusive business model
    - ✓ Set specific sustainability and social-economic impact ambitions
    - ✓ Unite industrial milling and business knowhow.

- ✓ Potential to combine local crops with fortification
- \- Requires organization and investments with (public) funds

In each case, also the spatial diversity of Sudan needs to be considered well, in respect of the diversity in agricultural (sourcing), infrastructural (roads, market linkages, industrial environment, etc) and cultural (demand, preferences) differences throughout Sudan. Simplified considerations are depicted in Figure 18.

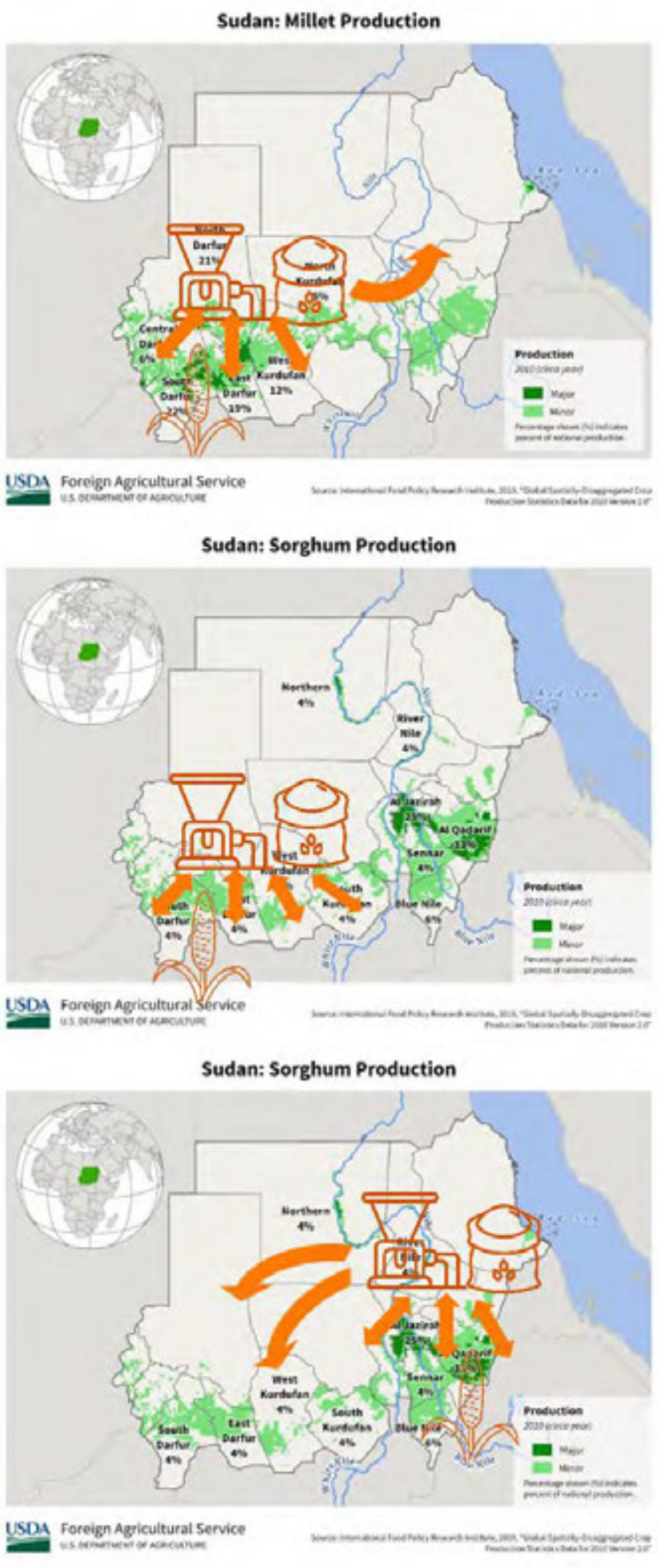

Figure 18 Simplified illustration of different locations considered. Directions of orange arrows illustrate sourcing and supply routes, added to crop maps (USDA 2024).

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Annex 1 List of actors and stakeholders involved, contacted and/or interviewed

Assignment and steering	Netherlands Enterprise Agency (RVO) Embassy of the Kingdom of the Netherlands in Sudan, evacuated (EKN)
Academia	University of Gaderef, Sudan Ahfad University for Women, Sudan Wageningen University & Research, the Netherlands
Private actors	DAL Food Group (including Sayga) SAY Group (Saeed group) Dr Dough, gluten-free products Sudanese SME bakeries in Egypt *The perspectives of SME bakeries in Sudan were explicitly asked via various development programmes as secondary sources (NGOs), e.g. NRC working with SME bakeries in Darfur and Kardofan.*
International institutions	Dutch Ministry of Foreign Affairs (MoFA) WFP Sudan FAO Sudan UN-DP
Aid/development NGOs	249 Startups Norwegian Refugee Council (NRC) ZOA international Bopinc SOS Sahel Sudan UNICEF
Other stakeholders	Clingendael Conflict Sensitivity Facility

Annex 2 Current cost of local crops

Increasing local crop sourcing requires addressing high production costs for local crops. Sorghum and millet production costs are affected by outdated agricultural practices, limited access to high-quality inputs, and poor infrastructure. Investment in mechanization, storage, and processing could enhance local crop viability. In addition, the ongoing conflict has further increased the prices (x300%).

Table 13 provides an overview of the current weekly prices for different types of sorghum, millet, and wheat in Sudan, focusing on both locally grown and imported varieties. Prices exclude the government fees of circa 10%.

In the sorghum market, several varieties are listed traded on the Algadarif market:

- Faterita had a high price of 750 SDG per kg and a low price of 700 SDG per kg. Reflecting a 5% decrease compared to the previous week's 762.5 SDG per kg.
- Dabar was priced higher, with a high of 1,150 SDG per kg and a low of 1,000 SDG per kg. The weekly average price was 1,075 SDG per kg, marking a 5% increase from the previous week.
- Hageen sorghum showed stable pricing, with a high of 850 SDG per kg and a low of 800 SDG per kg. The weekly average price remained at 825 SDG per kg, unchanged from the previous week.

Millet:

- The high price of millet was 1,700 SDG per kg, while the low price was 1,360 SDG per kg. The weekly average price stood at 1,530 SDG per kg, reflecting a significant 22% decrease compared to the previous week's 1,870 SDG per kg.

In the local wheat market, prices vary by source:

- Northern State: Prices ranged between 1,600 SDG and 1,450 SDG per kg, with a weekly average of 1,525 SDG, reflecting a 5% decrease compared to the previous week's 1,600 SDG per ton.
- River Nile State: Prices ranged from 1,500 SDG to 1,400 SDG per kg, with an average of 1,450 SDG per kg, unchanged from the previous week.
- Algazira - Almangel: Prices ranged from 1,300 SDG to 1,200 SDG per kg, with an average of 1,250 SDG per kg, unchanged from the previous week.

Cowpea and other peas:

Cowpea prices are difficult to obtain since the price is not monitored in the market monitoring reports. Since cowpeas are subsistence crops and not regarded as a premium pulse, we relied on the prices of other comparable pulses like pigeon pea. For January 2025 consumer market prices between 2700-2900 were reported for pigeon peas and chickpeas. The current prices range from 5,000-6,000 SDG per kg in Port Sudan local market (retail market price).

Table 13 Current prices of various crops in SDG per kg (week 44, 2024) (various sources*)*

	Commodity	Market	Weekly High Price /kg	Weekly Low price /kg	Current week AVG Price /kg	Last Week AVG/kg	Change %
Sorghum	Faterita	Algadarif state	750	700	725	762.5	-5%
	Dabar	Algadarif state	1,150	1,000	1,075	1,025	5%
	Hageen	Algadarif state	850	800	825	825	0%
Wheat	local wheat	Northern state	1,600	1,450	1,525	1,600	-5%
	local wheat	River Nile state	1,500	1,400	1,450	1,450	0%
	local wheat	Algazira -A lmangel	1,300	1,200	1,250	1,250	0%
Millet		Algadarif state	1,700	1,360	1,530	1,870	-22%
Pulses	Pigeon peas	Algadarif state	2,182	2,091	2,136	2,136	0%
	Pigeon peas	New Halfa	1,818	1,773	1,795	1,795	0%
	Chick peas	Algadarif state	2,200	2,100	2,150	2,150	0%
	Cow peas						

Annex 3 Markets in Sudan

Source: FEWS NET

Annex 4 Baking trials

Local crops – materials used

Three Sudanese Sorghum types and Millets were sourced by DAL, milled as wholemeal flours.

- Sorghum Dabar (white, premium) milled in Sudan, extraction 96.5%
- Sorghum Tabat (white) from Sudan, milled in Egypt, wholemeal extraction unknown
- Sorghum Faterita (red) from Sudan, milled in Sudan, extraction 96%
- Millets from Sudan, milled in Sudan, extraction 97%

Reference materials

- As representative imported refined wheat flour as supplied to bakeries by Sayga was used.
- For ghurassa, wholemeal wheat flour was obtained from the Egyptian market, Dobella, Al Masreq.

Ajin – Fermenting sorghum batter

Ajin – sorghum ferment

- Traditional breads and cereal products in the Sudan are often fermented by addition of Ajin.
- Ajin – Sorghum sourdough ferment, based on spontaneous fermentation, back-slopping* or more controlled with starting cultures, characterized by acid production with limited CO_2 production.
- Ajin is based on 20% sorghum and 80%water, fermented overnight to achieve a batter of pH=3.5-4.0.
- Sun-dried Ajin is produced and sold as Ajin powder starter-culture by informal businesses.
- The quality and safety of the ferment is judged by smelling and tasting the flavours (pleasant acidity without off-flavours)

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* In this study back-slopping technique was used

Aceda with Mulah

Source: taste of south sudan youtube channel

Sorghum Aceda

- Sorghum Aceda is based on ~50:50 fermented and native sorghum

Ingredients	Weight (g)
Ajin **	200
Boiling water	500
Sorghum flour *	30-50

- Procedure: Add Ajin (pH 3.5-4) to boiling water. Cook while stirring with *mufraka*. Add sorghum flour until desired consistency. Continue stirring and cooking until a piece remains cohesive in water.

* Tabat sorghum flour

** Ajin, Sorghum ferment pH=3.79, 20% sorghum 80%water

Millet Aceda

- Thick porridge Aceda can also be millet-based.
- No ferment used, soda is added for yellow colour and alkaline flavour.

Ingredients	Weight (g)
Millet flour	250
Water	400
Salt	5
Boiling water	450
Baking soda	0.5

- Procedure: Mix millet and other ingredients with cold water, and add to boiling water. Cook while stirring with *mufraka*, until smooth and thick.

Mulah

Millet aceda Sorghum aceda

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Medida

- Medida is a sweet, thin, drinkable porridge, based on Millet, with a silky-smooth texture.

Ingredients	Weight (g)
Millet flour	90
Water	150
Milk	450
Sugar	60
Salt	1.3
Baking soda	0.5

- Dissolve the millet flour in water. Bring the milk to Boil. Add millet slurry and other ingredients and stir until cooked.

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Kisra

kisra - process

- A smooth batter is obtained by mixing Sorghum flour with Ajin and water in a vessel using a *mufraka* (a wooden, t-shaped stirring tool).
- The batter is fermented for 2hrs at 28°C/90%RH.
- Water is added to obtain the right viscosity before baking.
- Some batter is poured on one side of the hot baking plate, lightly greased with oil.
- The batter is spread-out in zig-zag pattern to obtain a few mm thick layer at the whole baking surface.
- The palm leaf scraper used for spreading, called *gergeriba*, is kept in a cup of water to rinse after each spreading.
- When the sides of the kisra starts to curl, the kisra can be pealed-off the hot surface. They should be light in colour and still soft and pliable

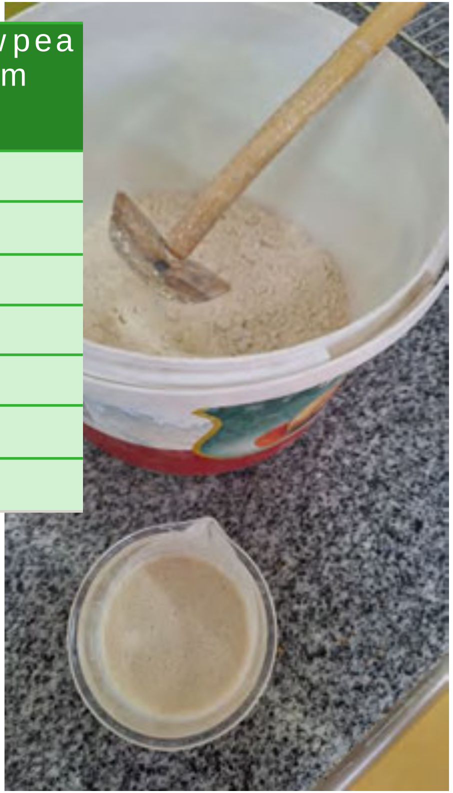
kisra - process





kisra – test recipes

Ingredients	Reference sorghum-wheat	Sorghum-cowpea 4% psyllium	Sorghum-cowpea 1% psyllium
Sorghum flour Tabat *	70	90.5	90.5
Wheat flour (refined)	30		
Cowpea flour Glenda		9.5	4.75
Psyllium fibre		4	1
Ajin **	100	100+25	100
Water	100	100+85	100
Additional water	*25*		13.5



* Sorghum from Sudan, wholemeal milled in Egypt
** Ajin, Sorghum ferment pH=3.79, 20% sorghum 80%water

Kisra - experimental

- Sorghum+wheat smooth thin batter

- Sorghum+cowpea+4% psyllium, too thick, short dough-like and lumpy

- Sorghum+cowpea+1% psyllium, bit thicker, and fluffy

Correction of viscosity was empirically done by varying water addition, not optimized

Kisra - experimental

- Ajin is typically used for acidification, whereas the gas formation is considered of less importance. However, in 2hrs fermentation, quite some gas bubbles are formed.
- In these experiments, the kisra batters with cowpea and psyllium seemed to retain more bubbles, and more fluffy substance. This might be caused by the composition and or viscosity differences.

Sorghum+cowpea+1% psyllium kisra batter after 2 hrs fermentation

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kisra products

- *Important note: kisra baking is a craft, and we were not experienced in the process*.
- The reference of sorghum+wheat was nice and thin, had a nice acidic flavour and had a bit a closed elastic surface (less desired)
- The sorghum+cowpea+1% psyllium was also nice and thin and had a nice acidic flavour and no beany flavour. The texture was very nice, only the visible dark specks of cowpea hull were disliked

Kisra – conclusions and recommendations

- Kisra is originally made from sorghum, but nowadays contains ~30% wheat flour for cohesiveness.
- 94% sorghum-5% cowpea-1% psyllium provided very nice kisra without wheat.
- Flavour and texture are good.
- In the appearance, the small specks of cowpea hull are disliked, dehulled pulse flour may be recommended


kisra from sorghum-cowpea 1% psyllium, with mullah

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Ghurassa

Ghurassa - process

- A thick batter is obtained by mixing all ingredients in a vessel using a *mufraka* (a wooden, t-shaped stirring tool).
- The batter is fermented for 45-60 minutes at 28°C/90%RH.
- The thick batter is poured on a hot plate, and smoothened by fingers in an outwards spiral, to obtain an even thickness of the disk of about 1 cm.
- The disk is baked on both sides on medium fire, to avoid overbaking.




Ghurassa – test recipes

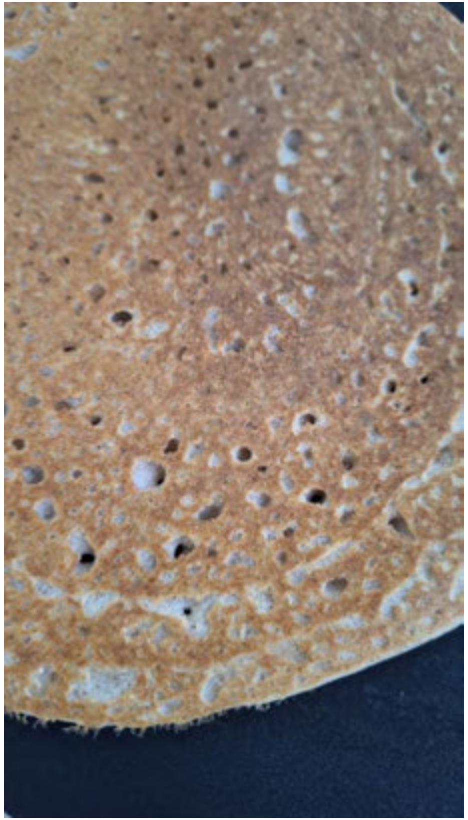
Ingredients	Reference wholewheat	Wheat-cowpea	Sorghum-cowpea	Sorghum-cowpea
Wholewheat flour *	300	270		
Sorghum Dabar			246	266
Cowpea Flour (Glenda)		30	30	30
Psylium fibre			24**	4
Yeast instant	1.5	3	3	3
Salt	1	1	1	1
Water	420	420	570**	420

- Reference wholewheat bit too gummy and chewy, bit undercooked
- Wheat with cowpea provides very fluffy aerated texture, bit pronounced pulse-flavour, but very nice overall.
- Sorghum with cowpea has a bit less elastic and gritty inside texture, but especially the crispy parts are very pleasant in taste and texture

* Wholegrain wheat fine 'ghurassa' flour Egypt market
** Sorghum with 8% psyllium absorbed too much water – test aborted

Ghurassa – conclusions

- Inclusion of cowpea in wheat ghurassa has potential.
- Wholegrain sorghum-cowpea-psyllium (8%) has a very high water retention, which is not positive for ghurassa baking and makes it difficult to bake it well (remains a bit wet/gummy).
- With lower amount of psyllium, sorghum with cowpea has potential for ghurassa baking.



Baladi bread

Baladi bread from imported wheat (reference)

Ingredients	Weight (g)
Refined wheat flour (Sayga)	100
Water	75*
Salt	0.7
Instant yeast	1

- Mixing in spiral mixer: 3 min slow speed, 4 min high speed.
- Bulk fermentation 5 min at bench.
- Scaling 80 gram pieces & rounding by hand, place on wheat bran.
- Rest for 20-25 min.
- Flatten-stretch dough pieces by hand to 130-150 mm diameter.
- Proof for 30 minutes at 28°C/90%RH.
- Bake @340°C at stone oven floor for 6-7 minutes.

* Was a bit too high, very sticky dough, 70% water would be better

Baladi bread from imported wheat (reference)



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Baladi bread with local crops initial tests

- As a start, the Ugandan ingredients and formulation for tin breads (loaves) was used.
- Since baladi is a softer dough, with higher water%, an additional variation with higher water% was tested as well.

Ingredients	1. Normal water	2. Extra water
Sorghum red FT2022-128	100	100
Cowpea Flour (Glenda) FT2019-269	19	19
Cassava starch FT2024-339	100	100
Psyllium fibre FT 2024-196	16	16
Instant dry yeast	4	4
Salt	1.5	1.5
Sucrose	2	2
Vegetable oil	8	8
Water	238	299

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Baladi bread with local crops initial tests

- All dry ingredients are mixed, water is added and stirred with a spoon.
- Dough mixing is very short and easy, as no mechanical development is needed.
- The cohesive dough forms through hydration (due to psyllium).
- Dough was well well handable and shapable/pliable, but doesn't have the elasticity of wheat (gluten).
- Dough sheets with thickness between ~4 mm and ~1.5 cm were rolled and fermented on bran for 30 min.

Baladi bread with local crops initial tests

- Baladi and other flat breads are available in many thickness, and the oven temperature is very important.
- We started at oven of 230°C, as a compromise between the normal baking temperature of the gluten-free tin breads (180°C) and wheat-based baladi and other flat breads (330°C).
- Also baking on a hot plate/griddle was tested.

Baladi bread with local crops initial tests

- With normal water content, baking at oven floor @230°C worked well
- Disks of ~1 cm baked well and provided dense crumb structure.
- Thick disks of ~1.5 cm yielded nice porous breads, although the crumb was still a bit gummy after 8 min baking.

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Baladi bread with local crops initial tests

- Very interestingly, the very thin discs of ~4mm thickness pillowed / puffed very well during baking, like a pita bread.
- Provided nice soft bread, like Arabic bread

Baladi bread with local crops initial tests

- With higher water content, baking was challenging
- Breads with nice porous crumb structures were obtained, but very long baking time was needed, due to the high water content. The thick disk needed 24 min and still the crumb was very moist.

Baladi bread with local Sudanese crops

- The recipe based on Ugandan crops shows good potential for baladi and other Sudanese breads.
- Focus on the normal (already high) water content with rather stiff dough, and include besides 230°C also higher baking temperature of 330°C.
- Sorghum – test different Sudanese varieties
- Cowpea – well available in Sudan and nutritionally desirable
- Cassava – very cheap source of carbohydrates in tropical regions, not in Sudan. Sweet potato is available, and will be tested. Since in Sudan, sorghum and millet are the main local crops, the focus will be to use these as main ingredients.

Baladi based on Sudanese sorghum and millet

- Sorghum and millet were used as main ingredients, with cowpea and psyllium, water adjusted subjectively to reach equal dough consistency.

Ingredients	3. Dabar	6. Faterita	4. Millet
Sorghum/millet	100	100	100
Cowpea Flour (Glenda)	9.5	9.5	9.5
Psyllium fibre	8	8	8
Instant dry yeast	2	2	2
Salt	1	1	1
Sucrose	1	0*	1
Vegetable oil	4	4	4
Water	150.5	149	125

- All doughs were well handable. Millet very silky and less sticky.

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* In view of the sweet taste of Faterita, no sugar was added

Baladi based on Sudanese sorghum and millet

- Dabar gives a nice porous structure.
- Mild and sweet taste.
- Very soft and resilient texture

- Millet gives a nice porous structure, with some pocketing.
- Mild millet flavour.
- Very nice soft and resilient texture

- Faterita gives a bit denser crumb structure.
- Nice typical faterita taste
- More gritty texture

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Baladi based on Sudanese sorghum and millet

Sorghum based doughs show very nice pillowing effect during baking at 330°C. Very pleasant texture. The inner crumb structure is very thin. Interesting potential, but we focussed more on baladi texture.

Examples shown made from Dabar based dough (#3.)

Baladi based on Sudanese sorghum and millet

- Baking of the sorghum- and millet-based doughs in thin disks on a hot plate/griddle provided very nice chapati-type flat breads.
- The texture of these breads is very nice, cohesive and rollable. However, the product is not common in Sudan, but could be a very nice new snack, especially with honey.

Examples shown made from Dabar based dough (#3.)

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Including sweet potato in Sorghum Baladi

- Can sweet potato flour be included in the recipe?
- Lower water absorption sweet potato flour

Ingredients	3. Dabar	5. Dabar sweet potato
Sorghum	100	50
Sweet Potato flour	-	50
Cowpea Flour (Glenda)	9.5	9.5
Psyllium fibre	8	8
Instant dry yeast	2	2
Salt	1	1
Sucrose	1	0.5
Vegetable oil	4	4
Water	150.5	135

Including sweet potato in Sorghum Baladi

- Including sweet potato flour works very well, although the crust colour gets too dark during baking at 330°C, 230°C worked well.
- The structure is very nice and open. The texture is very soft also after a day stored.
- Gives a very sweet taste, masking the sorghum flavour. Too sweet with savoury dishes – Lower level may work very well!

Effect of Ajin on Sorghum Baladi

- Ajin included in the recipe, keeping sorghum and water constant.

Ingredients	3. Dabar	7. Dabar + Ajin
Sorghum	100	90
Ajin (20% sorghum)		50
Cowpea Flour (Glenda)	9.5	9.5
Psyllium fibre	8	8
Instant dry yeast	2	1
Salt	1	1
Sucrose	1	1
Vegetable oil	4	4
Water	150.5	110

- The dough with Ajin was very supple, but clearly stiffer and less sticky, indicating a change in functionality

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Effect of Ajin on Sorghum Baladi

- The bread ajin seems denser – in line with expectation that Ajin gives limited CO_2
- Very nice effect on crust colour (warm) and pronouncing the sorghum flavour. Highly preferred
- Direct effect of the fermented sorghum in the ajin, or effect of lower pH on sorghum, cowpea and/or psyllium functionality?
- Fermentation may functionalize sorghum flour based on Ali (2024)

Ali, Taylor, Emmambux (2024) Effects of sourdough-type fermentation and sorghum type on the techno-functional properties of the batter used for kisra, a fermented flatbread, Journal of Cereal Science https://doi.org/10.1016/j.jcs.2024.103937

Effect of Soda on Millet Baladi

- Inspired by the addition of soda for making Millet Aceda, soda was used in replacement of yeast in Millet Baladi.
- Due to the soda, the millet dough had an intense yellowish colour, was very pliable and non-sticky.
- The breads obtained the distinct alkaline-millet taste which is highly appreciated in Sudan.
- Very promising result.

Ingredients	4. Millet	8. Millet+soda
Millet	100	100
Cowpea Flour (Glenda)	9.5	9.5
Psyllium fibre	8	8
Instant dry yeast	2	-
Soda (sodium bicarbonate)	-	1
Salt	1	0.75
Sucrose	1	0.5
Vegetable oil	4	4
Water	**125**	**125**

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Conclusions and recommendations Baladi

- Sorghum and Millets can be used to replace imported wheat in baladi bread, when using psyllium as functional ingredient.
- Cowpea was included for nutritional improvement.
- The appearance differs from wheat, but taste and texture are very pleasant and fit with Sudanese preferences (subjectively tested).
- Sweet potato (~10%?) seems very promising for nice taste, colour and crumb softness.
- The use of Ajin (or lactic acid fermentation in general) and soda (alkaline fermentation) hold particular promises for further developments of attractive and nutritional products.

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