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Access to Quality Seed, Credit, and Extension Services are Key Factors Influencing the Adoption of Improved Wheat Production Technologies in the Irrigated, Heat-Prone, Arid Environments of Sudan

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Abstract: Successful strategies that can contribute to poverty reduction and improve the livelihoods of the poor, particularly in Sub-Saharan Africa (SSA), are critically needed to address the technology adoption constraints. The objectives of this study were to assess the adoption rate of improved technologies and management practices and to identify the key factors influencing their adoption in the major wheat-producing areas of Sudan's irrigated, dry, and heat-prone environments. A farm survey was conducted in 2021 using a structured questionnaire that included all recommended technological options for optimum and sustainable wheat production. A total of 300 farmers, 93, 101, and 106 from Northern (NS), Kassala (KS), and Gezira (GS) states, respectively, were selected and interviewed. Besides descriptive statistics, a binary logistic model was used to identify the socioeconomic and production factors affecting farmers' perceptions of improved and recommended technological options. The study found a wide range of adoption rates depending on the specific technology practice and the area surveyed. The lowest adoption rate was observed for land preparation (6.5%) in NS. Adoption rates ranging from 26-100% were observed for technologies such as sowing date, seed rate, seed treatment, awareness of released varieties, nitrogen and phosphorus fertilizers application, and chemical weed control. The difference in the productivity of technological options adopters was significant (P = 0.015) compared to non-adopters. The binary logistic regression results showed that five out of seven explanatory variables hypothesized to influence wheat farmers' perceptions on the decision to adopt improved and recommended technologies significantly influenced farmers' decision to adopt the technologies. In particular, access to quality seed, financial credit, and extension services were found to be the most critical determinants of adopting improved technologies. Approaches that bring together all stakeholders along the crop value chain, including policymakers, to jointly analyse, identify, and prioritize challenges, develop and apply solutions and work plans using feedback and learning mechanisms are expected to increase farmer awareness and adoption of improved technologies, ultimately leading to sustainable wheat production.

Keywords: adoption rate; improved technologies; binary logistic; adopters; non-adopters; Sudan; sustainability.

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1. Introduction

Agricultural productivity gains have significantly contributed to economic growth and poverty reduction in many parts of the world, but these gains have been much more limited in Sub-Saharan Africa [1–3]. Increased technology adoption has the potential to contribute to economic growth and poverty alleviation amongst the poor, especially in sub-Saharan Africa (SSA), provided that successful strategies for addressing the constraints on their adoption are followed [1]. The adoption of the innovation platform approach in a number of SSA countries proved to be an effective method for adopting and applying improved agricultural technologies and offered a practical model of how stakeholders, including farmers, can act and interact to address common concerns, share responsibilities and obligations, and achieve their goals [4–7].

Sudan is a predominately agricultural economy. Agriculture is Sudan's most important economic sector in terms of its contribution to both GDP and employment. In 2016, agriculture contributed about 31.5% of GDP, employed about 70% of the population and provided the livelihood for almost all rural people [8]. Sudan has vast and diverse agricultural resources that provide various means of sustaining the people's livelihood. Both irrigated and rainfed agriculture exist in Sudan. Sudan's irrigated schemes are among the largest in the world. Irrigation water resources include the Blue Nile, the White Nile, other territories, and seasonal rivers, lakes, and swamps.

Wheat (*Triticum aestivum* L.) is the most widely grown crop in the world and the second largest calorie source behind maize [9]. In Africa, the gap between wheat supply and consumption is steadily increasing. For instance, during the period 2013-2022, Africa produced an average of about 27.1 million tons of wheat and imported an average of about 45.8 million tons per year with an average value of 13.5 billion US$ (https://www.fao.org/faostat/en/#data, accessed on February 1, 2024).

Wheat production in Sudan started in the fertile alluvial soils of the Nile in the Northern and River Nile States, where winter is relatively longer and cooler. Since the 1960s, however, wheat production has extended southward, and the crop is now cultivated in the central plains of the country at latitude 14-15° N [10]. It is considered as a strategic cereal food crop and ranked second in terms of consumption after sorghum [6,10,11]. Since the early 1960s, wheat consumption in Sudan has been sharply increasing as a result of the ever-increasing demand for wheat arising from rapid urbanization, changes in consumer habits, high consumer subsidies, population and income growth [12]. As a result of these factors, wheat consumption in the Sudan increased from about 220 thousand tons in 1971 to over 800 thousand tons in 1991 and reached about 2.4 million tons in 2016 [8]. This situation entailed importing 80% of wheat to reduce the gap between local production and consumption.

Wheat production has grown slowly, primarily because of the low use of modern inputs and poor crop management practices**.** Average yields are generally low compared to other producing countries as affected by many production and environmental factors. One of the primary reasons for low wheat yield and the wide gap between potential and farmers' yield is the slow adoption of the recommended packages of improved practices [13]. However, with continual research and technology transfer, notable improvements have been achieved [10]. Due to activities related to the generation of agricultural technologies, dissemination and adoption of farming technologies, and capacity strengthening of some projects, there was an increase in yield and income of wheat-producing farmer [5].

Generally, the management practices of the farmers are relatively poor, the crop cultivation procedures are inappropriate, and inputs such as certified seeds, fertilizers, weeding, irrigation, and pesticides are minimally used in recommended doses and times. Traditional varieties are grown in some parts of the country, resulting in low current productivity (2.6 tons/ha). Fluctuating wheat prices and the typically low prices at harvest time when there is no government intervention are also serious problems for producers. Hence, wheat production is a function of all technical, financial, and socioeconomic factors. Therefore, to enhance and expand wheat production, farmers need to improve the efficiency of poor cultural practices used by farmers. In doing so, impact assessment of production efficiency is essential to determine the areas that require improvements in the production activities, which necessitates conducting such important axe-anti and ex-post studies.

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In addition to the factors mentioned above, climate change poses major challenges for sustainable wheat production [14]. In Sudan, upward trends in both the annual and growing season temperatures were found when trend analyses of temperature indicators and wheat yields were used [15]. Wheat yields in Sudan were found to be negatively associated with both day and night temperatures during the growing season, and the negative effect of rising temperature on wheat yield has increased in recent years [15]. It is paramount to note that in stressful environments such as those of most wheat-producing areas in Sudan, integrated crop management strategies should be strictly followed for sustainable and profitable wheat production. In the context of this changing climate, several factors are known to influence farmers' adaptation and adoption of improved technologies. The farmer's experience in farming, their access to extension services and climate information, access to subsidies, farm and family size, gender, and electricity for irrigation were found to be the significant factors affecting adaptation decisions in several SSA countries [16–19]. Lack of information on adaptation methods, financial constraints, limited access to climate information, and low price of the product represented major adaptation barriers [17,19,20].

The objectives of this study are to assess the rate of adoption of improved technologies and management practices and to identify the key factors influencing the adoption of these technologies in the major wheat-producing areas of Sudan. The study identifies that access to quality seed, credit, and extension services are the key determinants of the adoption of improved wheat production technologies in the irrigated heat-prone environments of Sudan.

2. Materials and Methods

The research methodology includes the study areas, survey and data collection design, sample size and sampling of the villages, attribution and quality of data, analytical techniques, and data analyses.

2.1. Study areas

The study areas included three major wheat-producing areas in Sudan: Gezira, Northern, and Kassala States (Figure 1). The Gezira Scheme in the Gezira State is the largest area of wheat in Sudan (about 155,000 ha in season 2020/2021). The Gezira Scheme consists of two major areas: the Gezira area and the Managil extension. The Gezira area is about 0.504 million hectares lying contiguous to the Blue Nile, and the Managil extension, developed between the years 1957 and 1962, covers an area of about 0.370 million hectares lying to the southwest of Gezira Scheme [21]. The study areas also included the Northern State, which represents the traditional wheat area in Sudan, and the New Halfa Agricultural Corporation in Kassala State as one of the important wheat areas in Sudan, which was established in the early 1960s to accommodate the displaced people from Wadi Halfa area in Northern State. The three areas together represented more than 80% of the total wheat area in Sudan during 2019/20-2020/21 [22].

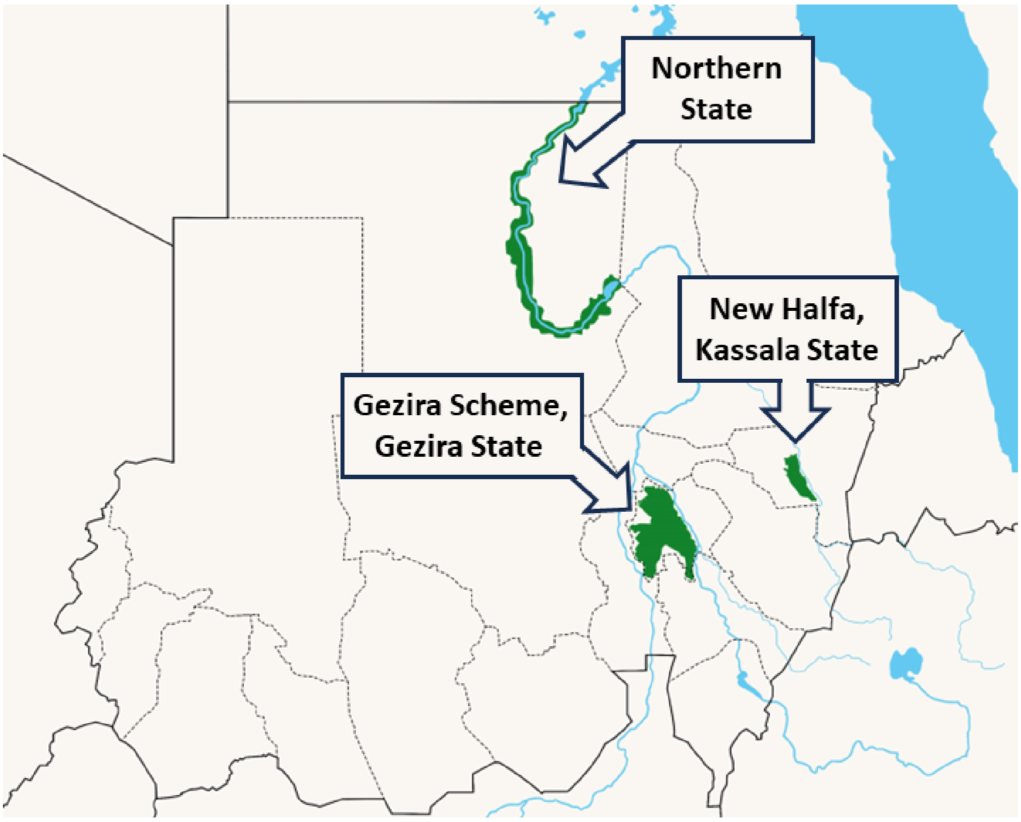

Figure 1. The locations of the three major wheat-producing areas in Sudan (Northern, Gezira, and Kassala States) were included in the farm survey.

2.2. Design of the survey and data collection

The wheat production technologies and the prospects of farmers' activities for wheat were considered to determine the sources of production inefficiency in the targeted areas and, finally, to identify and prioritize the constraints for optimal use of resources. A questionnaire was designed, data was collected, analytical tools were selected, threats to sustainable production were considered, and an outline for the strategy, design, and implementation of long-term research activities was provided. Rapid Rural Appraisal (RRA) was conducted by visiting the selected sites to assess the situation and collect the basic relevant information related to wheat production. Based on RRA results and considering the objectives of this study, a comprehensive questionnaire has been designed for data collection. The questionnaire included almost all the main variables needed to investigate wheat production practices and efficiency. A multistage stratified random sampling technique was used to collect the primary data from various wheat producers.

2.3. Sample size and areas

Two major considerations influence the choice of any sampling design: the desire to avoid bias in the selection procedures and to achieve the maximum precision for a given outlay of resources to achieve the stated objectives. The sample size has been determined according to the variation of the target populations. A purposive random sampling technique was used. Various farmer groups were interviewed, representing 300 wheat farmers from the three selected areas (Table 1). Respondent farmers within these areas have been selected and interviewed. The farm survey was conducted in 2021 under the project "Development of Climate Change Resilient Innovative Technologies for Sustainable Wheat Production in the Dry and Heat Prone Agro-ecologies of Sudan and Sub-Saharan Africa." The collected data consisted of items related to the cost of production, current production practices at all levels, and the main factors affecting crop production.

Table 1. Number of farmers interviewed, disaggregated by states and type of intervention

	Respondent				
	Control sites		Intervention sites		Total
Study area	No	%	No	%	No
Northern State	66	71.0	27	29.0	93
Kassala State	39	38.6	62	61.4	101
Gezira State	60	56.6	46	43.4	106
Total	165	55.0	135	45.0	300

2.4. Attribution and quality of data

The questionnaire was designed precisely to reflect the objective of the study. Questions were formulated to facilitate the calculation of the required indicators that assess the production and current practices dominantly applied by farmers for wheat cultivation in targeted areas. Well-trained enumerators collected the primary data. The interviews with different stakeholders proved that all respondents had the same information about implementing activities in the same area.

2.5. Analytical Techniques and Data Analysis Tools

Appropriate analytical tools and models were used to derive indicators that reflect the progress and the impact of crop management practices on wheat production and farming systems to measure the success of using improved technologies in the study areas, as reflected by the adoption of best technologies, to mitigate the drastic effect of traditional farming systems, and to improve the household incomes of the rural communities.

The information was appropriately arranged, and the Statistical Package for Social Sciences (SPSS version 20) was used to analyze the collected data. Cross-tabulation with chi-square analysis was used to test the null hypotheses (the row and column variables are unrelated) whenever this hypothesis makes sense for a two-way variable. The columns represented the surveyed areas, whereas rows represented the socio-economic and production variables.

A paired sample test was used to compare the wheat productivity of farms where improved technologies and management were applied with the farms where improved technologies and management were not applied. The binary logistic model was used to analyze the factors affecting wheat farmers' perceptions of the improved and recommended technologies.

2.6. Selection of the Model

The logit model was used because the properties of estimation procedures are desirable for evaluating the adoption rate situation [23]. Binary logistic regression predicts a categorical (usually dichotomous) variable from a set of predictor variables [24]. It was adopted here to analyze the factors affecting the wheat farmers' perceptions towards the improved and recommended technologies. The dependent variable in this model was represented by a dummy variable that reflect whether the wheat farmers are adopters of improved technologies or non-adopters. The independent variables included the farmers' socioeconomic characteristics and wheat production factors. The socioeconomic characteristics were wheat farming experience, education level, wheat area, and land tenure, whereas production factors included access to quality seeds, access to credit, and access to extension services. The coefficient values measure the expected change in the logit for a unit change in the corresponding independent variable, other independent variables being equal [25]. The coefficient sign indicates the direction of the variable effect on the logit. A positive value indicates an increase in the likelihood that a farmer will change from the baseline group to the alternative option [25]. The SPSS software 20 was used to analyze the data. The general logistic model uses the following equation:

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$$logit(Pi) = \log\left\{\frac{Pi}{1 - Pi}\right\} = a + \beta Xi$$

$$In(ODDS) = In\left(\frac{\grave{y}}{1 - \grave{y}}\right) = a + bX$$

$$ODDS = e^{a + bX}$$

$$\grave{y} = \frac{ODDS}{1 + ODDS}$$

$$ODDSRatio = \frac{ODDS\ (Pi)}{ODDS\ (1 - P)i}$$

Where;

Pi = response probabilities to be modeled,

a = intercept parameter,

β = vector of slope parameters,

Xi = vector of explanatory variables.

Specifically, the logit model in this study takes the following form:

$$In\left[\frac{P_i}{1 - P_i}\right] = b_0 + b_1YR_i + b_2YE_i + b_3WA_i + b_4LT_i + b_5SA_i + b_6RF_i + b_7EP_i + U_i$$

Where;

Pi = Probability that the ith wheat farmers acknowledge improvement in the production situation after adopting improved technologies,

1-Pi = Probability that the ith wheat farmers do not acknowledge any improvement in the production after adopting improved technologies,

YR = Wheat farmers experience (years)

YE = Wheat farmers education level (years)

WA = Wheat area (ha)

LT = Land tenure (Farmers owned their land = 1, otherwise = 0)

SA = Wheat quality seeds access (seeds accessible = 1, otherwise =0)

RF = Received finance (received finance for wheat production = 1, otherwise = 0)

EP = Extension services provision (received extension services = 1, otherwise = 0)

bj = Logit coefficients (j = 0, 1... 12), and

Ui = Random disturbances.

2.7. Trade-Off Analyses of Improved Technologies and Management

The most important wheat production technologies and management practices were selected for comparative analyses between farmers who adopted improved technologies and non-adopters. Table 2 illustrates these technologies and management practices. It is worth noting that a farmer who adopted seven out of nine of these improved technologies and management practices was considered an adopter.

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Table 2. Production technologies and management have been chosen for comparative analyses between farmers who adopted improved technologies and non-adopter farmers

Production practices and management	Recommended technologies and management	Unrecommended technologies and management
Land preparation	3 ridging + leveling Chisel ploughing + ridging + leveling Chisel ploughing + ridging + leveling Disc harrowing+ ridging + leveling	Disc ploughing + ridging + leveling Disc ploughing + 2 ridging + leveling Disc ploughing+3 ridging+ leveling
Released varieties	Used recommended varieties	Used non-recommended varieties
Seed sources	Scheme administration Agricultural bank ARC Seed companies	Market Farmers own seeds Seeds from other farmers Unknown sources
Seed rate	119 kg to 143 kg/hectare	143 to 177 kg/hectare
Sowing date	1 to 14 November 15 to 30 November	1 to 14 December 15 to 30 December
DAP fertilization	119 kg DAP/hectare	178.5kg DAP/hectare 238 kg DAP/hectare
Urea fertilization	238 kg urea/hectare	179 kg urea/hectare 278 kg/ urea/hectare 119 kg urea/hectare 357 kg urea/hectare
Optimum numbers of irrigation	More than 5 irrigations	Less than 5 irrigations
Herbicide application	Herbicides applied	Herbicides not applied

3. Results and discussion

3.1. Socioeconomic Characteristics of the Sampled Farmers

The main socio-economic characteristics of the sampled farmers in Northern State, Kassala State (New Halfa Agricultural Corporation), and Gezira State (Gezira Scheme) are presented in Table 3. The survey results showed that 15.7% of the sampled farmers in the three states were illiterate, while 36 and 11% of them had secondary and university education levels, respectively. The primary, intermediate, and secondary school levels constituted most of the farmers in the three areas (72.1, 77.2, and 70.7% in the Northern, Kassala, and Gezira States, respectively).

Crop production was the main job for the most sampled farmers (85%), whereas mixed crop production and animal husbandry constituted only 7.0%. Almost 90% of the farmers privately owned their farms, while land sharing and renting represented < 10.0% (Table 3). The average experience of the farmers in wheat cultivation in the three states was 26.8 years in Northern State, 22.7 years in Kassala State, and 21.9 years in Gezira State (Table 3). These characteristics show that the sampled farmers have enough experience to conduct physical work and coordinate and manage farming activities.

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Table 3. Socioeconomic characteristics of the respondent farmers in three surveyed wheat-growing areas in Sudan

	Characteristics	Northern State	Kassala State	Gezira State	The three states
Education level	Illiterate	17.2	11.9	17.9	15.7
	Primary	44.1	16.8	29.2	29.7
	Intermediate	0.0	0.0	21.7	7.7
	Secondary	28.0	60.4	19.8	36.0
	University	10.8	10.9	11.3	11.0
	Total	100.0	100.0	100.0	100.0
	Chi-square		95.60, *P < 0.0001*		
Main job	Crop production	81.8	97.0	76.4	85.0
	Animal production	0.0	0.0	8.5	3.0
	Famer and trader	5.4	0.0	9.5	5.0
	Farmer and animal production	12.9	3.0	5.6	7.0
	Chi-square		62.88, *P < 0.0001*		
Land tenure	Own	92.5	87.1	89.6	89.6
	Share	2.2	8.9	1.9	4.3
	Rent in	2.2	3.0	0.9	2.0
	Own and rent in	3.2	1.0	6.6	3.7
	Own and share	0.0	0.0	0.9	0.3
	Chi-square			16.79, *P = 0.079*	
Farmers experience in wheat cultivation (years)	Mean	26.8	22.7	21.9	24.2
	Standard deviation	9.2	11.1	11.2	9.5
	CV	0.34	0.49	0.51	0.39

3.2. Wheat productivity statistics during season 2020/2021

The descriptive statistics showed that the average wheat productivity for adopter farmers was recorded at about 2.93 tons/ha, compared to 2.59 tons/ha for non-adopter farmers. A paired sampled t-test used to compare the productivity of the adopter and non-adopter farmers in the three states showed that the difference was significant (P = 0.015) in the productivity of the two farmer groups (Table 4).

Table 4. Descriptive Statistics of wheat productivity of adopter and non-adopter farmers in season 2020/2021

Statistics	Adopters	Non-adopters
Number of farmers	224	76
Mean yield (t/ha)	2.93	2.59
Std. Deviation	0.81	0.69
C.V	0.28	0.27
t- statistics	P = 0.015	

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3.3. Adoption of the Technologies

The adoption rate of different technologies and management practices are shown in Table 5. The adoption rates for land preparation varied from 6.5% in the Northern State to 57.4 and 54.7% in the Kassala and Gezira States, respectively. The comparatively high adoption rate in Kassala and Gezira states could be due to the administrative other agricultural systems setup, the land share, farm size, and the availability of the agricultural machinery through the public and private sectors, as well as the inclusion of land preparation in the credit service provided through the management of both schemes.

The adoption rate for the use of released varieties was 100% in Gezira and Kassala states, whereas 11.8% of the farmers still use local landraces/cultivars in the Northern State (Table 5). The low adoption rate of released varieties in the NS could be attributed to the farmers' preference for the traditional cultivars, which are considered more suitable for locally processed food. In addition, the lack of administrative setup, such as those in Gezira and Kassala states, could be linked to the low level of credit provision in NS. However, although released varieties are adopted in both Gezira and Kassala states, 59.4 and 78.3% of the farmers in both states, respectively, used their own stored seeds or grains from the market as their seed source, while 90.3% of the farmers in Northern State obtained their seeds from the recommended sources of the quality seed (Table 5). In NS, almost all locally produced wheat is consumed by the farmers' households or within the local community. As a result, farmers tend to obtain high-quality seed from reliable sources, as they are keen to produce high-quality grain without mixing with other varieties.

The percentage of farmers adopting the recommended seed rate varied from 73.1% in Northern State to 83.0% in Gezira and 92.1% in Kassala State. The relatively high level of seed rate adoption in Kassala and Gezira states could also be attributed to the involvement of both scheme administrations in facilitating seed distribution and sowing, in addition to the partial credit service provision. The adoption rate for recommended sowing date was generally high, with the highest rate recorded in Kassala (99.0%), followed by Northern State (96.8%) and Gezira Scheme (93.6%).

Regarding crop nutrition, the adoption rate of P fertilizer was high in the three areas; however, only 55.4% of the farmers in Kassala State adopted the recommended dose of N fertilizer (Table 5). The adoption rates for N fertilizer were 78.5 and 83.0% in NS and Gezira, respectively.

The adoption of using herbicides to control weeds in the wheat fields was 100% in the Gezira and 98% in Kassala; however, 35.5% of the farmers in the Northern State were non-adopters of the herbicide use. This might be linked to socioeconomic factors such as the use of weeds for animal feeding in the Northern State, where usually the lands are limited and intensive agriculture is practiced, in addition to the high cost of production due to the high cost of pumping the irrigation water.

All farmers in Kassala State adopted the application of the recommended number of irrigations for wheat cultivation, whereas 82.8 and 86.8% of the farmers adopted this management practice in the Northern and Gezira States, respectively (Table 5). Not adopting the recommended irrigation might be linked to the high cost associated with irrigation in the Northern State and probably with the unavailability of irrigation water in some areas in the Gezira at the right time.

The adoption of different technology options and management practices is known to be affected by many factors. The adoption of bread wheat and chickpea varieties in Ethiopia was found to be influenced by gender, education, background, years of farming, ownership of the land, extension contact, distance to the nearest market, tropical livestock unit, participation in farm demonstrations, and access to inputs and the annual income of the household [26–28]. Similarly, the adoption and intensity of use of bread wheat technology package were found to be positively affected by gender, livestock size, and crop production objective, whereas age, farm size, annual off-farm and non-farm income, location, and distance to farmer training center had a significant negative influence on the adoption [29]. However, Oyetunde-Usman [3] reviewed the heterogeneity in three factors affecting the adoption of agricultural technologies, namely land, extension and social institutions, and gender, in selected West and East African countries, and concluded that the promotion of agricultural technologies should be relative to the farm attributes of the household conditioned on probable

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factors that may drive their adoption. It has been found that, along with age, education level, and farmers' perceptions, an increase in extension visits significantly increased the likelihood that a farmer would adopt no-till conservation agriculture (CA), whereas an increase in land size was negatively associated with the adoption of no-till CA [30].

Table 5. The adoption rate of different recommended improved technologies in Northern, Kassala, and Gezira states

Production technology	Farmers category	Northern State	Kassala State	Gezira State	Mean	Chi-square (P value)
Land preparation	Adopters	6.5	57.4	54.7	39.5	65.55 (< 0.001)
	Non-adopters	93.5	42.6	45.3	60.5	
Released varieties	Adopters	88.2	100.0	100.0	96.1	25.42 (<0.001)
	Non-adopters	11.8	0.0	0.0	3.9	
Seed source	Adopters	90.3	40.6	21.7	50.9	97.98 (< 0.001)
	Non-adopters	9.7	59.4	78.3	49.1	
Seed rate	Adopters	73.1	92.1	83.0	82.7	12.34 (0.002)
	Non-adopters	26.9	7.9	17.0	17.3	
Sowing date	Adopters	96.8	99.0	84.9	93.6	34.36 (< 0.001)
	Non-adopters	3.2	1.0	15.1	6.4	
P fertilizer (TSP or DAP)	Adopters	100.0	100.0	92.5	97.5	15.04 (< 0.001)
	Non-adopters	0.0	0.0	7.5	2.5	
N fertilizer (Urea)	Adopters	78.5	55.4	83.0	72.3	27.13 (< 0.001)
	Non-adopters	21.5	44.6	17.0	27.7	
Herbicide application	Adopters	64.5	98.0	100.0	87.5	4.39 (< 0.001)
	Non-adopters	35.5	2.0	0.0	12.5	
Numbers of irrigation	Adopters	82.8	100.0	86.8	89.9	19.58 (< 0.001)
	Non-adopters	17.2	0.0	13.2	10.1	
Mean	Adopters	75.6	82.5	78.5	78.9	
	Non-adopters	24.4	17.5	21.5	21.1	

3.4. Binary Logistic Regression

The results of binary logistic regression are presented in Table 6. The results showed that out of the seven explanatory variables hypothesized to affect the perception of wheat farmers towards adoption of improved and recommended technological options, five variables, namely, farmers' education level, land tenure, access to quality seeds, access to financial support and access to extension services significantly affected farmers decision to adopt improved technologies. On the other hand, farming experience had no significant effect on the adoption rate, whereas the wheat area showed a positive, non-significant effect ($P = 0.079$).

Three variables, access to quality seeds, access to financial support, and access to extension services, were found to be highly significantly and positively correlated with the farmers' perceptions of improved technology adoption. This highly positive relationship may be explained by the importance of the availability and accessibility of these inputs and services in this regard.

The odds ratio ranged from 1.019 for farming experience to 6.681 for access to extension services. Odds ratios of > 4.0 were also found for access to quality seed, access to financial support, and owning the farming land (Table 6).

The high value of the odd ratio supports the higher probability of the variable influencing the adoption rate. For example, the odds ratio of access to extension services was 6.681, implying that the farmers who received or have access to extension services are 6.861 times more likely to adopt the improved technologies than those who didn't receive the extension services.

Adopting improved technologies for different crops is known to be affected by many socioeconomic, financial, and technical factors. Using a meta-analysis of 367 regression models from

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published literature on the adoption of agricultural technology in the developing world, Ruzzante et al. [31] found that farmer education, household size, land size, access to credit, land tenure, access to extension services, and organization membership positively correlate with the adoption of many agricultural technologies. Meanwhile, in Arsi Highlands of the Oromia Region, Ethiopia, the decision of smallholder farmers to adopt the improved wheat varieties was significantly and positively influenced by seed availability, row planting, and distance to the cooperative, while the intensity of adoption was found to be negatively related to the proportion of farmland allotted for wheat production [32].

To promote the adoption of multiple practices, it was recommended that training of farmers on climate-smart agricultural practices should be incorporated into all agricultural and climate change projects [33]. In Sudan, both public sectors and parastatal and private seed companies produce seeds for different crops. However, As is the case in many SSA countries, the seed sector in Sudan faces a wide range of constraints, such as ineffective and inefficient regulatory and policy frameworks, inappropriate institutional and organizational arrangements, infrastructural and technical deficiencies in seed production, processing, quality assurance, marketing, and distribution, inadequately trained and skilled personnel, and the difficult socio-economic circumstances of the farmers. Because the seed supply system in Sudan has been severely weakened since the 1990s, a wheat seed system review was conducted to identify critical bottlenecks in the wheat seed sector and provide a future roadmap for seed production, processing, distribution, and marketing [6]. As a result, strong public-private partnerships (PPPs) have been established, through which different categories of seeds have been produced and distributed to farmers [34].

Likewise, extension services are delivered through a network of extension administrations across all country states. In addition, large agricultural schemes and corporations, such as the Gezira Scheme and New Halfa Agricultural Corporation, have their own internal setup for extension services. However, the availability of funds, facilities, and the efficiency of these bodies are key factors for proper service delivery.

The main credit provider in the country is the Agricultural Bank of Sudan, which provides mostly in-kind support, such as seeds and fertilizers, with some monetary support for harvesting and transporting the product to designated areas. However, this is highly dependent on the policy and regulatory frameworks. As a result, farmers in many areas lack adequate access to credit and support. To overcome these challenges, an innovation platform approach has been proposed to bring together all stakeholders, including credit, service, and input providers, to create a win-win environment [6]. As a result, Hassan et al. [5] reported that farmers' participation in farmer-managed demonstration plots, field days, and farmers' field schools within the innovation platforms significantly enhanced the adoption of the recommended wheat packages. The adoption of improved wheat production technologies increased wheat productivity and farmers' incomes, contributing to increased food security and improved producers' livelihoods [5]. Linking the applied research for development with the adoption of agricultural technology through effective extension and technology transfer activities can significantly improve productivity and raise the income of farm households [5,6].

Table 6. The binary logistic regression of the farmers' perception of wheat improved technology adoption in Sudan.

Explanatory variables	Coefficient	Odds ratio	P-Value
Farming experience	0.019	1.019	0.256
Education level	0.126	1.134	0.005
Wheat area	0.09	1.095	0.079
Land tenure	1.481	4.395	0.025
Access to quality seeds	1.615	5.027	0.0
Access to financial support	1.524	4.588	0.0
Access to extension services	1.899	6.681	0.0
Constant	-5.092	0.006	0.0
Chi-square (P-value)		< 0.0001	

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[1]Log likelihood	204.416
[2]Cox & Snell R Square	0.357
[3]Nagelkerke R Square	0.528
n	300

[1]The Log Likelihood statistic measures how poorly the model predicts the decisions. The smaller the statistic, the better the model. [2]The Cox & Snell R^2 can be interpreted like R^2in a multiple regression. [3]The Nagelkerke R^2 can reach a maximum of 1.

In addition to improved technologies, further improvement in wheat production/output from the current levels would be possible if farmers use the available inputs efficiently. Many factors were found to affect technical efficiency, including the level of education, training, age of the household head, availability and access to improved seed and credit, crop insurance, off-farm income, crop share rates, etc. [35–37]. Significant inefficiencies were found in wheat farms in the main wheat-producing areas of Sudan [38]. They found that the average technological gap ratios for Gezira, Kassala, and Northern states were 0.82, 0.50, and 0.75, respectively. Chebil et al. [11] reported that due to the low technological gap at Kassala state, improved technology generation and dissemination, such as integrated pest management, are required to improve wheat productivity. On the other hand, wheat productivity could be improved in Gezira and Northern states through more efficient use of inputs and existing technologies. Since then, a number of improved technologies have been made available, especially in Kassala State, including new rust resistance varieties, sowing methods, and chemical control of rust diseases [39–41].

4. Conclusions

Adopting integrated crop management is crucial for sustainable and economically viable crop production in areas under or expected to be under stress due to climate change.   Under the dry heat stress environments of Sudan, improved technological options have been developed and need to be adopted by the farmers for sustainable and profitable wheat production. This study found a wide range of adoption rates depending on the specific technology practice and the area surveyed. The study also found that access to quality seed, financial credit, and extension services were the most important determinants of adopting improved technologies. It is expected that the adoption of approaches and methodologies that bring together all stakeholders along the wheat value chain, including policymakers, to jointly identify, analyze, and prioritize challenges, develop and implement solutions and work plans, using feedback, reflection, and lesson-learning mechanisms, could raise farmers' awareness and enhance adopting improved technologies.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Figure S1: title; Table S1: title; Video S1: title.

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