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Transitions towards sustainable agriculture: The case of wheat-based production systems in Egypt

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Ahmed Abdalla

aus

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Referent: Prof. Dr. Mathias Becker

Korreferent: Prof. Dr. Christian Borgemeister

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Dedication

I dedicate this work in loving tribute to my mother. Your unwavering support, boundless love, and endless sacrifices have shaped me into who I am today. Thiswork stands as a testament to your remarkable influence on my life.

Abstract

Egypt, the world's largest wheat importer, confronts a significant disparity between its wheat production and consumption. The country's food security is increasingly precarious with an annual production of only half of its 20 million tons of wheat consumption. The population growth rate of 1.94% per year further exacerbates the situation, projecting a near doubling of wheat demand by 2050. Egypt relies heavily on Russia and Ukraine, major wheat exporters, for its wheat supply. These imports predominantly flow through Black Sea ports, but ongoing conflicts disrupt these vital supply chains, driving up food prices and deepening food security concerns in Egypt and other import-dependent nations. In response to these challenges, the Egyptian government has strategically aimed for wheat self- sufficiency, recognizing the geopolitical implications of stable wheat production. The study addressed three primary research topics:

(1) The first part of this study analyzes wheat cultivation trends in Egypt from 2000 to 2020, to identify both external pressures and system-immanent drivers that have shaped wheat self-sufficiency trends over the past two decades, and offering insights into the required actions for achieving self-sufficiency in the future.

(2) As increased domestic wheat production must confront the complex interplay of factors that influence farming practices and crop yields, the second part of this study investigates wheat productivity in the Nile Delta. The findings reveal that smallholder farmers, who are key contributors to Egypt's wheat production, face challenges related to poor access to knowledge on modern farming practices, access to resources, and market structures. The average farmer, aged 56 with 30 years of experience, holds small land holdings of approximately 1.05 hectares, yielding an average of 6.4 metric tons per hectare. Only a fraction of the cropland is allocated to wheat. The large variability in grain yields and the resulting uncertainty in the outcome of investments in modern practices represents a risk for farmers and acts as a disincentive to technology adoption. Multiple factors influence this yield variability, with cropping practices playing a substantial role. The study emphasizes that farmers' inadequate knowledge of modern agronomic practices, unbalanced fertilizer use, and irrigation inefficiencies significantly affect yields and largely explain much of the observed yield variability. The type of summer crops preceding wheat and the frequency of irrigation emerged as major factors affecting yield variations. Addressing these factors requires a comprehensive approach, including fiscal incentives to encourage larger wheat cultivation areas, sustainable agricultural practices, and improved irrigation efficiency.

(3) Millions of Egyptians rely on wheat-based *baladi* bread as a staple in their daily diet. While smallholders along the Nile have cultivated wheat for millennia, the wheat supply-demand ratio has drastically changed. The third part of this study aimed to identifies system-

immanent factors such as subsistence needs and animal husbandry intensity, alongside external factors including policies as determinants of smallholders' decisions to increase or decrease wheat cultivation. Some of these factors vary across regions within the Nile River Delta, suggesting the need for tailored interventions, targeting specific social-ecological niches.

The results underline the importance of agricultural policies, (subsidized) production inputs, climate conditions, and global wheat supply chains as critical external pressure forces shaping land use and the share of the land cultivated with wheat. System-immanent drivers of land use and wheat production comprise the on-farm resource endowment, spatially variable domestic wheat supply prices, and low and variable wheat yields. This complexity of external and system-immanent determinant of production and drivers of change suggest the adoption of a holistic strategy to enhance wheat self-sufficiency in Egypt. Addressing the challenges of agricultural policies, resource access, and market structures is crucial to making wheat production more appealing to smallholders. Encouraging sustainable practices, such as a balanced nutrient supply and improved irrigation can increase yields and reduce variabilities. The study underscores the importance of removing constraints and increasing support to boost domestic production and alleviate Egypt's dependence on increasingly unreliable imports of wheat.

Zusammenfassung

Ägypten, der weltweit größte Importeur von Weizen, steht einer erheblichen Diskrepanz zwischen seiner Weizenproduktion und seinem Verbrauch gegenüber. Die Lebensmittelsicherheit des Landes ist zunehmend prekär, da die jährliche Produktion nur die Hälfte seines 20-Millionen-Tonnen- Weizenverbrauchs ausmacht. Die jährliche Bevölkerungswachstumsrate von 1,94 % verschärft die Situation weiter und lässt eine nahezu Verdopplung der Weizennachfrage bis 2050 erwarten. Ägypten ist stark von Russland und der Ukraine, beide wichtige Weizenexportländern, für seine Weizenversorgung abhängig. Diese Importe fließen hauptsächlich über Häfen im Schwarzen Meer, doch laufende Konflikte stören diese vitalen Lieferketten, treiben die Lebensmittelpreise in die Höhe und vertiefen die Bedenken hinsichtlich der Lebensmittelsicherheit in Ägypten und anderen importabhängigen Nationen. Als Reaktion auf diese Herausforderungen strebt die ägyptische Regierung strategisch die Selbstversorgung mit Weizen an und erkennt die geopolitischen Auswirkungen und die Bedeutung einer stabilen lokalen Weizenproduktion an. Die Studie umfasst drei Hauptziele:

(1) Der erste Teil dieser Studie analysiert die Trends im Weizenanbau in Ägypten von 2000 bis 2020, um sowohl externe Druckfaktoren als auch systemimmanente Treiber zu identifizieren, die die Trends zur Weizenselbstversorgung in den letzten beiden Jahrzehnten geprägt haben. Die Studie gibt Einblicke in die erforderlichen Maßnahmen, um zukünftige nachhaltige Selbstversorgung zu erreichen.

(2) Die Steigerung der inländischen Weizenproduktion erfordert eine gezielte Ansprache der komplexen Wechselwirkung von Faktoren, welche landwirtschaftliche Praktiken und Ernteerträge beeinflussen. Daher untersucht der zweite Teil dieser Studie die Weizenproduktivität pro Flächeneinheit im Nildelta. Die Ergebnisse zeigen, dass Kleinbauern, die maßgeblich zur Weizenproduktion Ägyptens beitragen, mit Herausforderungen in Bezug auf landwirtschaftliche Praktiken, Ressourcenzugang und Marktstrukturen konfrontiert sind. Der durchschnittliche Landwirt ist 56 Jahre alt, verfügt über 30 Jahre Erfahrung, bewirtschaftet kleine Flächen von etwa 1,05 Hektar und erzielt durchschnittlich einen Ertrag von 6,4 metrische Tonnen pro Hektar. Nur ein Bruchteil der Anbauflächen wird dem Weizenanbau gewidmet. Erträge sind sehr variable, was ein Risikofaktor für Landwirte darstellt und abschreckend für die Annahme verbesserter Anbauverfahren wirkt. Diese Ertragsvariationen werden von mehreren Faktoren beeinflusst, wobei landwirtschaftliche Praktiken eine wesentliche Rolle spielen. Die Studie betont, dass unzureichendes Wissen der Landwirte über moderne agronomische Praktiken, unausgewogene Düngemittelverwendung und ineffiziente Bewässerung die Weizen-Ertragsvariabilität signifikant beeinflussen. Die Art der Vorkultur in Weizenrotationen und die Häufigkeit der Bewässerung erwiesen sich als wichtige Faktoren, die die Ertragsvariabilität bedingen. Die Überwindung solcher limitierender Faktoren erfordert einen umfassenden Ansatz, einschließlich finanzieller Anreize zur Förderung größerer Weizenanbauflächen, nachhaltiger

landwirtschaftlicher Praktiken und verbesserter Bewässerungseffizienz.

(3) Millionen von Ägyptern sind auf weizenbasiertes *Baladi*-Brot als Grundnahrungsmittel angewiesen, und Kleinbauern entlang des Nils bauen seit Jahrtausenden Weizen an. Allerdings hat sich das Verhältnis von Weizenangebot und -nachfrage in der rezenten Vergangenheit drastisch verändert. Der dritte Teil dieser Studie zielt darauf ab, systemimmanente Faktoren wie Subsistenzbedürfnisse und die Intensität der Viehhaltung sowie externe Faktoren wie Politiken zu identifizieren, welche die Entscheidungen der Kleinbauern zur Steigerung oder Verringerung des Weizenanbaus bestimmen. Viele dieser Faktoren variieren räumlich zwischen den Regionen im Nil-Delta, was maßgeschneiderter Interventionen erfordert. Die Ergebnisse unterstreichen einerseits landwirtschaftliche Politiken, (subventionierte) Produktionsmittel, Klimabedingungen und globale Weizenlieferketten als kritische Bestimmungsfaktoren für die Anbaufläche von Weizen. Die Flächenerträge und die Produktivität andererseits werden vornehmlich durch systemimmanente Treiber, wie den regional variablen inländische Weizenpreis und die Ressourcenausstattung der Betriebe bedingt.

Der Weg zur Steigerung der Weizenselbstversorgung in Ägypten erfordert eine ganzheitliche Strategie. Die Bewältigung der Herausforderungen landwirtschaftlicher Politiken, des Zugangs zu Ressourcen und der Marktstrukturen ist entscheidend, um die Weizenproduktion für Kleinbauern attraktiver zu gestalten. Nachhaltige Praktiken wie eine ausgewogene Nährstoffversorgung und verbesserte Bewässerung müssen gefördert werden. Die Studie unterstreicht die Bedeutung der Beseitigung von Hindernissen und der Erhöhung von Unterstützungsdiensten, um die inländische Produktion zu steigern und Ägyptens Abhängigkeit von zunehmend unzuverlässigen Importen zu verringern.

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List of abbreviations

CBE	The Central Bank of Egypt
CAPMAS	The Central Agency for Public Mobilization and Statistics
EGP	Egyptian Pound
FAO	Food and Agriculture Organization of the United Nations
ha	Hectare
MALR	The Ministry of Agriculture and Land Reclamation in Egypt
PCA	Principal Component analysis
SSR	Self- Sufficiency Ratio
t	Ton
USD	Unites States Dollar
UNCTAD	The United Nations Conference on Trade and Development

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1 Introduction

1.1 Background

According to the Food and Agriculture Organization (FAO) [1], the global population is projected to reach 9 billion individuals by 2050, which will require a 60% increase in food production compared to the 2005-2007 period. In response to this rapid demographic growth and evolving consumer demands, transformative changes in agricultural production are necessary. It is crucial for the agricultural sector to adapt accordingly [1]. However, it is anticipated that the required increase in primaryproduction will primarily come from productivity gains, such as higher yields and intensified land use, rather than expanding agricultural areas [2]. This intensification process must be carried out sustainably, especially in developing countries. Here, sustainability refers to the capacity of agricultural systems to meet both current and future needs in a dynamic manner [3]. Achieving sustainable intensification entails more than just meeting the growing food demand. Production systems must also be capable of delivering consistent outcomes under varying environmental conditions, including adapting to emerging biotic and abiotic stresses, as well as changing climate patterns [1]. Furthermore, these production systems must address farmers' aspirations, such as income generation, labor efficiency, and social recognition, while also meeting the evolving expectations of society as a whole. These expectations encompass environmental protection, safe and nutritious food, adherence to social standards, and more. Consequently, agriculture must continuously adjust its agronomic practices, production and value chain organization, and overall agricultural production system to accommodate these diverse and often conflicting requirements and demands. This involves various aspects such as crop selection, rotation strategies, integration practices, and overall system orientation [1].

The green revolution implemented during the late 1960s and early 1970s, was a response to the pressing hunger crisis of the 1950s and 1960s. Its primary objective was to increase food crop production through the utilization of high-yielding genotypes that were responsive to inputs, alongside intensive agrochemical and irrigation practices. This approach resulted in improved food supply and reduced prices [4]. However, the excessive use of agrochemicals had detrimental effects on both environmental and human health, leading to a decline in agrobiodiversity and an increased dependency on external agents and processes [4]. Currently, global production trends are aimed at achieving resource efficiency, social and environmental integration, biodiversity conservation, and nature protection, while still prioritizing food security. This integrated approach is commonly referred to as 'One Health' [5]. Ensuring food security, which involves the availability of safe and nutritious food for all individuals at all times, remains a central concern [5]. The concept of food securityencompasses four fundamental dimensions: availability, access, utilization, and stability. Availability pertains to the domestic production of food in adequate quantities and of suitable quality. Access focuses on individual accessibility to essential resources and entitlements necessary for a nutritious diet. Stability refers to the consistent and reliable availability of food for populations or individuals. Utilization encompasses the contribution of food to a well-rounded diet and overall healthcare [5].

According to the Food and Agriculture Organization of the United Nations (FAO) [6], sustainable food systems encompass the provision of food security and nutrition for all while concurrently ensuring the preservation of economic, social, and environmental foundations for future generations. This necessitates the system's economic viability, societal benefits, and positive or neutral impact on the natural environment. Achieving these objectives demands ongoing adaptation across all sectors of agriculture.

While adaptation encompasses primary food production, processing, marketing, and responsible consumption in response to evolving emands, the initial production of food crops serves as the fundamental step in the food system. Thus, this research seeks to investigate the historical, present, and future trends and changes in food crop production systems to facilitate the transition toward sustainable agriculture. Crop production systems have experienced and will continue to undergo modifications to address evolving challenges and expectations. These modifications may involve shifts in crop varieties, land and crop management practices, adoption of technological innovations, or the reorganization of value chains [7]. When significant and abrupt changes transpire in agricultural production, they are commonly referred to as system shifts [8]. These system shifts or alterations in agricultural production systems are influenced by various external factors, including policies, climate change, and societal expectations, as well as internal drivers such as available resources, production factors, and individual aspirations [9].

1.2 Agriculture sector in Egypt

Egypt, with an estimated land area of 1 million km2, is predominantly reliant on agriculture. However, 97% of its land comprises desert [10]. Agricultural practices encompassed an estimated land area of around 3.5 million hectares including undergone reclamation from both coastal areas and deserts [10]. The agriculture sector significantly contributes to the country's economy, accounting for approximately 14%of the total GDP and employing around 31% of the national workforce [11]. The livelihoods of approximately 53% of the rural population, who directly or indirectly depend on agricultural activities, are supported by this sector [11]. However, despite its role in employment and export earnings, Egyptian agriculture faces numerous challenges and threats. Among these challenges is the persistent and escalating water scarcity, accompanied by land degradation, climate change, rural poverty, outdated farming practices and technologies, and limited access to information and extension services for farmers [11]. Moreover, the absence of policies conducive to promoting sustainable food production worsens these environmental and institutionalconstraints. Nevertheless, Egypt benefits from a favorable sub-tropical winter-rain agro-ecological zone, fertile soil in the Nile valley, and access to water from the Nile River, enabling the cultivation of a diverse range of agricultural crops [11].

Egypt's agricultural sector exhibits a diverse range of crops encompassing staple food crops such as wheat and rice, as well as a wide variety of high-value vegetablesand fruit trees like citrus fruits and dates [12]. Furthermore, Egypt cultivates forage species such as clover and alfalfa for ruminant feed, alongside industrial crops like cotton, sugarcane, and sunflower, which are cultivated extensively [12]. The selection of crops in Egypt is influenced by the prevailing climatic conditions, with wheat, onions, and alfalfa assuming significance during the cooler and wetter winter season,while irrigated rice and cotton serve as the primary crops during the hot and dry summer season. Egypt has gained international recognition for its substantial production of high-quality export commodities, including citrus fruits, dates, tomatoes,and watermelon [13]. However, despite its agricultural potential, Egypt confront numerous challenges in maximizing production. Only a small portion, approximately 3.5%, of the country's land area is suitable for agriculture, with the majority consistingof desert [14]. Moreover, high production costs, recurrent drought events, inadequateirrigation infrastructure, and land fragmentation exert adverse effects on rural livelihoods and contribute to rural-urban migration. Consequently, Egypt heavily relies on imports, particularly for essential commodities like wheat, to meet the increasing and evolving national demand [14].

1.3 Land and water challenges

Soil degradation and water scarcity have long presented persistent and formidable challenges within Egypt [13]. The historical prominence of water scarcity, particularlyin terms of high-quality water, continues to pose significant obstacles for the country's agricultural sector [13]. As time has progressed, Egypt's agricultural production systems have undergone continual transformations, primarily influenced by the availability and utilization of irrigation water sourced from the Nile River [14]. Consequently, these systems have necessitated adaptation to the biophysical realities of water scarcity and shifts in soil quality, all while responding to local and global societal demands, political priorities, and the aspirations of farmers. Simultaneously, the agriculture sector in Egypt faces substantial challenges stemming from the combined impacts of climate change and inadequate land management. Such challenges manifest as the escalating prevalence of soil salinity, declining soil fertility, soil erosion, and drought [14]. Furthermore, improper handling of irrigation water and agrochemicals exacerbates water pollution [14]. The encroachment of civil infrastructure and the expansion of residential areas contributeto the consumption of fertile land, intensifying the trend of urbanization. Additionally, the fragmentation of farmland poses a grave threat to Egyptian agriculture as it diminishes the land holdings of small-scale farmers [14]. The majority of farmers in Egypt fall within the smallholder category, with over 80% owning less than 2 hectares of cropland, and 50% possessing even less than 0.4 hectares [11].

Egypt heavily relies on the Nile River as its primary water source for agricultural purposes, constituting approximately 78% of the country's total available water resources, which amounts to approximately 55.5 km3 of freshwater annually [13]. The remaining 22% of water resources are derived from in-situ rainfall, underground water, and an escalating dependence on recycling agriculture drainage and wastewater [15]. Groundwater is predominantly utilized for irrigation in the northern region of the Delta; however, excessive extraction has resulted in the intrusion of saltwater into the lower aquifer, leading to the presence of brackish and saline water [14]. By 2014, nearly half of the agricultural land area in the Delta exhibited conditions of brackish to saline groundwater [14].

As the population of Egypt continues to undergo rapid growth and the area of irrigated agricultural land expands, the availability of water per capita per year has experienced a decline from 1024 m3 in 2002 to approximately 900 m3 in 2010, and currently stands at around 850 m3 [16]. Furthermore, the reliability of water supply from the Nile River is expected to become increasingly uncertain due to the impact of climate change and the construction of the Great Ethiopian Renaissance Dam upstream on the Blue Nile [17].

1.4 Wheat role in Egypt

Wheat plays a significant historical and political role in Egypt, serving as the most crucial crop [1]. It provides approximately one-third of the daily caloric intake and 45% of the protein intake for Egyptians through wheat-based food [16]. The importance of wheat in Egypt's society was evident during the "bread riots" in 1977, when hundredsof thousands of Egyptians protested against the government's decision to cut subsidies on bread and other essential commodities [18]. Tragically, the protests resulted in the deaths of 77 people and numerous injuries. Furthermore, during the Egyptian revolution in January 2011, one of the recurring slogans chanted by the protesters was "Bread, freedom, and social justice," highlighting the significance of bread as a basic necessity. The availability and quality of traditional Egyptian bread *(baladi)* were key factors that contributed to the revolution in 2011. Consequently, wheat has a long-standing and highly political significance in Egypt, and subsidized bread prices have remained unchanged for several decades [18].

In Egypt, wheat is produced both in the “old land” on alluvial clay soil in the Nile Valley and the Delta with an estimated 1.2 million hectares, but also in the “new land”, comprising recently reclaimed and newly cultivated areas on sandy soil on the fringes of the Nile Valley and the Sahara desert with an estimated 0,26 million hectares [19].Attainable yields of wheat vary widely between sites mainly in relation to soil types and access to water. As a consequence, also the production systems, agronomic practices and market links differ in space and time [20]. Different wheat-basedproduction systems may differentially contribute to the government's vison of transiting towards a sustainable agriculture by achieving food self-sufficiency while increasing resource use efficiency and protecting human health. To date it remains unclear however, which production system type, what kind of required transitions and which innovations and policy formulations will help farmers in Egypt to produce morewheat in a more sustainable way [20].

Despite occupying approximately 33% or nearly 1.5 million hectares of the total winter crop area in Egypt [2], domestic wheat production falls short of meeting half of the country's consumption, resulting in the need for imports to bridge the gap [21]. In 2018, Egypt became the largest global importer of wheat, bringing in 12 million tons, and projections indicate that wheat imports will exceed 15 million tons due to current demographic growth rates. To address this dependency on imports, the Egyptian government's strategic document, "Egypt Sustainable Development Strategy Towards 2030," outlines the vision of achieving over 80% self-sufficiency in agricultural products that significantly contribute to national consumption [22]. The strategy also emphasizes the imperative of improving water use efficiency, considering water scarcity as Egypt's most critical resource. In support of sustainablewheat production, the government provides subsidies for agricultural inputs, including improved seeds, irrigation water, and chemicals, aiming to incentivize farmers to adopt enhanced wheat technologies and increase production. Additionally, the government subsidizes the private sector along the wheat value chain, encompassingthe final product, "flat *baladi* Bread." [23]. The vision of the 2030 document emphasized the government's aspiration to attain 74% wheat self-sufficiency by 2017. However, the actual self-sufficiency ratio in 2017 was just 43% [21].

1.5 Smallholders and the agriculture policy in Egypt

In Egypt, the majority of farmers are classified as smallholders, with approximately 90% owning less than 2 hectares of cropland, and 50% possessing even less than 0.4 hectares [24]. Smallholder agriculture plays a significant role in terms of employment, food production, as well as land and water utilization. However, neoliberal policies implemented in Egypt over the past few decades have had significant consequences for the smallholder class. These policies involved the reduction or elimination of agricultural subsidies and technical support, the restriction of certain agricultural production areas, and the facilitation of imports of essential agricultural products for the domestic market [25]. Consequently, these measures have contributed to the fragmentation and reformation of the smallholder class, leading to an increased reliance on imported food, particularly for staple crops in the Egyptian diet such as wheat, maize, soybeans, red meat, and oilseeds [25]. Simultaneously, the Egyptian government has implemented policies to support the expansion of new lands, particularly reclaimed desert areas, and the cultivation of cash crops intended for the international market, including potatoes and citrus [26]. This shift has resulted in a specific form of smallholder economic integration, with a focus on production and processing for export markets, specifically in newly developed lands [26]. During this process, smallholders have engaged in competition and partnership with national and multinational companies in order to enter export markets, while family business groups and financial firms have diversified their operations by acquiring publicly owned agricultural corporations [25]. However, it should be noted that export markets have been more likely to exclude smallholders, particularly those who produce traditional crops for the domestic market [26]. Additionally, the agricultural sector in Egypt has faced significant challenges due to the massive waves of rural-to-urban migration and the loss of hundreds of thousandsof hectares of arable land each year, estimated at 224 thousand feddans annually (one feddan is equivalent to 0.42 hectares) [27]. Consequently, as a result of these policies and circumstances, Egypt has become the largest global importer of wheat [25].

In 2020, Egypt's wheat imports amounted to 13.5 million metric tons out of a total consumption of 20 million metric tons [28,29]. Russia and Ukraine were the primary wheat suppliers, accounting for 60-66% and 20-25% of imports, respectively, with Romania, France, and the United States following suit [29]. In 2021, Russia and Ukraine contributed 85% of Egypt's total wheat imports [28,29]. Approximately 61% of the Egyptian population, equivalent to 63.5 million people, rely on subsidized *baladi* bread through a state-subsidized food card system [29]. The Egyptian government has maintained the price of *baladi* bread at a subsidized fixed rate of EGP 0.05 per loaf (equivalent to USD 0.01 in January 2022) for the past three decades, which is significantly lower than the actual production costs [30]. Over time, the bread subsidyprogram has become a significant economic burden on the Egyptian state budget, with food subsidies alone reaching EGP 89 billion (USD 5.69 billion) in the fiscal year2019/20, and EGP 84.5 billion (USD 5.4 billion) in the 2020/21 fiscal year [31].

In contrast, during the 2022 financial year, the value of the Egyptian currency droppedsignificantly against the US dollar, with a depreciation of approximately 60% (from EGP 15.7 to US$ 1 in January 2022 to EGP 24.7 to US$ 1 in December 2022) [32]. This currency devaluation was a result of global inflation and the trade deficit in the Egyptian economy caused by high import dependency. Consequently, the Egyptian market experienced severe disruptions in the supply chain of essential commodities, coupled with significant price increases for food commodities due to the scarcity of foreign currencies, particularly the US dollar [33]. The recent report by the United Nations Conference on Trade and Development (UNCTAD) draws attention to the challenges faced by developing countries, including Egypt, that heavily rely on food imports. These nations are confronted with a dual burden of soaring food prices and a depreciation of their local currency against the US dollar, making it significantly difficult to prevent hunger among their populations [28]. The report indicates that in October 2022, the average global food prices increased by 89% compared to the average in 2020. Furthermore, the exchange rates of developing countries' national currencies against the US dollar rose between 10 and 46 %. As a result, estimated price increases range from 106 to 176%, representing more than double the prices in 2020 [28].

The impact of exchange rate fluctuations is identified as a major driver behind the escalating food import bills, contributing to inflation, loss of purchasing power, and food insecurity in these affected nations. Egypt, after Mauritius, Pakistan, and Ethiopia, stands as the fourth most affected country globally by the exchange rate effect. Notably, Egypt experienced a 112 % increase in its wheat import bill between 2020 and 2022 due to both currency devaluation and the surge in international wheat prices. Consequently, to import the same quantity of wheat as in 2020 (13.5 million metric tons), the additional costs are estimated at US$ 3 billion, which accounts for 20 % of Egypt's total food import bill [28].

The situation poses a significant threat to wheat imports and overall food security in Egypt, while exerting a considerable burden on the country's economy. Although the World Bank approved a US$500 million loan in June 2022 [29] to assist Egypt in ensuring continuous access to bread for vulnerable households through the Emergency Food Security and Resilience Support Project, concerns arise regarding the government's ability to meet the required quantities of wheat, animal feed, and other essential food commodities while maintaining social and political stability. However, it is important to note that this loan covers less than 20 % of the additional costs resulting from inflation and currency devaluation. The vision of reducing reliance on costly and increasingly unstable wheat imports through the promotion of domestic production emerges as the only viable solution to overcome these challenges and avert a hunger crisis in Egypt. Despite wheat occupying approximately 50% of the total winter-cultivated area in Egypt, with Egyptian varieties being among the highest yielding globally (8.5 tons/ha to 10.3 tons/ha) [27], the average yield per unit of land falls 25% below the expected yield due to inappropriate cultivation and irrigation practices (Second publication). Concurrently, smallholders in Egypt have gradually expanded the cultivation of alternative winter crops such as clover "Bersim," thus replacing areas previously dedicated to wheat [24].

This doctoral thesis focuses on investigating the transition towards sustainable agriculture within the context of Egypt's wheat-based system. The objective is to examine the interplay of social, economic, and environmental factors and their implications for food security, wheat self-sufficiency, and overall sustainability. Through an in-depth case study approach, this research aims to provide valuable insights, challenges, and strategies that can inform policy formulation and decision- making processes within Egypt's agricultural sector.

The study encompasses three primary objectives. Firstly, it aims to estimate the degree and trends of wheat self-sufficiency, production area, and productivity in Egypt from 2000 to 2020.

Additionally, it seeks to identify the external pressures and system-immanent drivers that impact the trend of wheat self-sufficiency. Secondly, the thesis assesses the existing production strategies employed in Egypt's wheat- based systems and investigates their effects on wheat productivity in four specific study areas within the Nile Delta region. The third objective is to determine the key factors that influence smallholders' decisions to cultivate wheat and adopt efficient farming practices. Furthermore, it evaluates the changes in these determinants over a two-decade period (2000-2020). By addressing these objectives, the research aimsto shed light on the underlying factors driving agricultural practices and decision- making processes among smallholders.

2 General Material and Methods

2.1 Study area

Approximately 57% of Egypt's wheat-producing land is located in the Nile Delta, specifically in the Beheira Governorate, as indicated by [19]. The Beheira Governorate, chosen as the study area for this research, is situated in the North- Western region of the Nile Delta and serves as a key hub for wheat production in Egypt. The agricultural practices employed by small-scale farmers in this governorate are representative of those utilized in other wheat-growing regions throughout the country. Geographically, the Beheira Governorate covers an area of 9,826 km2 west of the Rosetta branch of the River Nile. It is densely populated, accommodating approximately 7 million people, with over 70% of the population engaged in agricultural activities. The governorate has excellent connectivity to Cairo and Alexandria through four major highways. It comprises 13 centers, 14 cities, 84 rural municipalities, and 407 villages, as reported by [34].

Despite occupying only around 15% of Egypt's total agricultural land [35], the agricultural area within the Beheira Governorate contributes to 60-65% of the nation's overall wheat production. Wheat cultivation in Beheira involves rotational practices with irrigated summer crops and vegetables on relatively small land parcels located on the outskirts of urban areas, known as the "old land." Additionally, large land holdings in rural areas, referred to as the "new land," adopt partial pivot and spray irrigation in fallow rotation systems [36]. For the purpose of this study, four municipal divisions within the Beheira Governorate were selected as focal areas, considering factors such as water availability, market accessibility, and soil type. The research transect extends from the Al Mahmoudiya Division, encompassing 14 villages situated along the Rosetta branch of the Nile (representing a rural-moist scenario), tothe Kafr El Dawar Division, consisting of 31 villages located near major highways with excellent market access (representing an urban-moist scenario). The transect furtherextends to the Abu El Matamir Division, comprising 24 villages located on the desert margin (representing a rural-dry scenario), and concludes with the El Nubariyah Division, representing cultivated desert areas (representing an urban dry scenario) (Map 1). Within each of these study divisions along the transect, various wheat production and marketing methods have evolved over time in response to external pressures, including policies, water availability and pricing, input and product processes, as well as inherent drivers within the system such as the availability of production factors and farmers' perceptions. These factors have been systematically characterized and classified, as outlined by [37].

2.2.1 Data sources and methods of analysis

A mixed-methods research approach was employed in this study to collect both qualitative and quantitative data. The initial phase of the study primarily relied on secondary data obtained from various published and unpublished sources, including the Egyptian Ministry of Agriculture and Land Reclamation (MALR), the Central Agency for Public Mobilization and Statistics (CAPMAS), the United States Department of Agriculture (USDA), the Food and Agriculture Organization of the United Nations (FAO), and the World Bank. This involved conducting a content analysis of national and international surveys and reports, regulatory documents, grey literature, and journal articles published over approximately the last two decades.

To complement the secondary data, a combination of qualitative and quantitative methods was employed to gather primary data. Initially, 28 open-unstructured interviews were conducted with smallholders involved in wheat cultivation. Additionally, 12 open interviews were conducted with agricultural extension agents, and 8 interviews were carried out with individuals considered as experts in the field. Furthermore, 12 Focus Group Discussions (FGDs) were organized, and field observations were conducted using transect walks and participatory observation techniques. The research was conducted in four municipal divisions located in Beheira Governorate, Egypt, namely Al Mahmoudiyah, Kafr El Dawwar, Abu El Matamir, and El Nubariyah, which are situated in the Nile River delta in lower Egypt. Subsequently, structured questionnaire-based interviews were conducted with 246 wheat-growing smallholders, randomly selected during the agricultural season of 2020/2021. Structured questionnaires were employed to interview wheat-producing farmers, encompassing three distinct sections: (1) farmer attributes and resource endowment, (2) agronomic practices, and (3) farmer perceptions. To ensure the reliability of our questionnaires, we conducted a pre-test with 25 farmers across all four study areas. The section on agronomic practices within the survey covered various aspects such as crop rotations, seed sources, soil tillage, crop establishment, utilization of mineral and organic fertilizers, frequency of irrigation events, strategies for weed and pest control, harvesting methods, and the intended utilization of the produced wheat (sale or home consumption).

We employed a random selection method using official records obtained from the Ministry of Agriculture and Land Reclamation (MALR) in each study area to identify a total of 246 wheat growers [38]. These records consisted of comprehensive listingsof households engaged in wheat cultivation in each village. The selection of wheat growers in each municipal division was proportional to the corresponding farmer populations. The chosen number of participants was considered satisfactory to achieve the desired level of statistical significance and precision [39]. Specifically, this sample size enabled us to establish a 95% confidence interval with a margin of error of ±5%. Moreover, it ensured that data collection could be feasibly conducted within the study's timeline and available resources [40]. The data were subjected to descriptive statistical analysis. Frequency counts, percentages, and means were utilized to provide an account of the patterns and future prospects concerning wheat self-sufficiency, production, and yield. Two-way analysis of variance (ANOVA) and a linear regression model were employed to examine disparities in agronomic practices and wheat yields [39]. Subsequently, the key factors were computed and arranged inorder of importance based on the perspectives of small-scale farmers. This was accomplished by calculating an overall score for each factor through the summation of individual farmers' scores. Additionally, the percentage of the maximum possible score was determined to enable the ranking of factors from most to least significant. To evaluate the perceptions and attitudes of small-scale farmers, a five-point Likert Scale was utilized. Respondents were requested to indicate the extent of theiragreement or disagreement with specific statements, using a scale ranging from strongly agree (5) to strongly disagree (1). Furthermore, their assessment of external pressures and system-immanent drivers was measured on a scale ranging from verypoor (1) to excellent (5), while their perception of changes in the past two decades was evaluated on a scale ranging from much worse (1) to much better (5).

In the data analysis phase for the last part of the study, a comprehensive approach was taken to distill insights from both qualitative and quantitative data sources. Qualitative data collection encompassed 28 open interviews with wheat-growing smallholders, 12 interviews with agricultural extension agents, 8 interviews with agricultural cooperative representatives, and 12 focus group discussions (FGDs), enriched by participatory observations and transect walks. This rich qualitative data was subjected to systematic coding, identifying meaningful units and assigning descriptive codes to emerging themes. Triangulation was employed to bolster reliability, comparing data across sources. Pertinent quotations were meticulously selected to augment analysis with tangible examples. The synthesis of themes and supporting evidence yielded a coherent narrative aligned with research objectives [41]. On the quantitative front, STATA software facilitated descriptive statistics, portraying wheat production characteristics and smallholders' perceptions. A Principal Component Analysis (PCA) further discerned influential factors by transforming the high-dimensional dataset into a lower-dimensional representation while retaining vital information. Additionally, linear regression analysis explored relationships between PCA factors and distinct study areas, unraveling geographic influences on decision-making patterns. This combined analytical approach enrichedthe study's insights, painting a holistic picture of the intricate dynamics surrounding wheat production and smallholder decision-making in Egypt [42, 43].

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Chapter 4

Trends and Prospects of Change in Wheat Self-Sufficiency in Egypt

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Trends and Prospects of Change in WheatSelf-Sufficiency in Egypt

Abstract

Egypt is the largest wheat importer in the world; however, it produces only half of the 20 million tons of wheat that it consumes annually. The population of Egypt is currently growing by 1.94% per year, and projections predict that the demand for wheat will be nearly doubled by 2050. Russia and Ukraine are major wheat exporters to Egypt and globally, shipping grains from ports in the Black Sea. The ongoing conflict aggravates the already precarious food security situation in Egypt and many other import-dependent countries in Africa and Asia by disrupting supplies and accelerating food price hikes. Wheat is a strategic commodity in Egypt. Its production is a question of political stability. Against this backdrop, the Egyptian government declared gaining wheat self-sufficiency as a strategic aim. This study provides an overview of the degree and trends of cultivated wheat area,yield, production, and wheat self-sufficiency in Egypt between 2000 and 2020, followed by a qualitative analysis determining external pressures and system- immanent drivers that had an impact on wheat self-sufficiency in the past two decades in view of predicting future pathways to achieve wheat self-sufficiency in a sustainable way. The study underlines some critical external pressures such as agricultural policies, (subsidized) production inputs, climate conditions, global wheat supply chains, and system-immanent drivers such as domestic wheat supply prices and yields influencing the area of wheat cultivation and its productivity. There is a significant need to implement more effective and long-term sustainable agricultural policies in order to make wheat production in Egypt (more) attractive and feasible for smallholders again.

Keywords: Egypt; wheat; food security; self-sufficiency; sustainable agriculture

1. Introduction

Increasing population growth and changing consumer demands require changes in agricultural production and systems. In 2050, the world's population is estimated to reach 9 billion people, requiring a 60% higher food production than in 2005–2007 [1]. The agricultural sector has to respond to this challenge. The required increase in primary food production is expected to come from productivitygains (higher yields and increased land-use intensities) rather than from area expansion [2]. Egypt is an agriculture-based country. However, 97% of Egyptian land is desert. Out of the total land area of about 100 million ha, only about 3.5 million ha is used for agricultural production, including the "new lands" reclaimed from the desert in the last decades [3]. In addition to the massive scarcity of arable land and water shortage, the population growth rate in Egypt is one of the highest worldwide. The population is currently growing at a rate of 1.94%, adding about 2million people each year [4]. However, a favorable sub-tropical winter-rain climatecombined with fertile soils in the Nile valley and water supply by the Nile River permits Egypt to produce a large variety of crops, ranging from coarse grain to fruits and vegetables and export-oriented crops such as citrus. Agriculture contributes approximately 14% to the total GDP and absorbs about 31% of the national workforce. About 53% of the population lives in rural areas, with their livelihood directly or indirectly depending on agricultural activities [5]. Most farmers in Egypt are categorized as smallholders, with more than 80% of them owning less than 2 ha of cropland and 50% holding even less than 0.4 ha [5]. Smallholder agriculture contributes significantly to employment and food production, as well as land and water use.

Egypt's main crops in terms of cultivated area are wheat, rice, and a large diversityof vegetables and fruit trees (i.e., citrus and dates). Egypt also produces forage species for feeding ruminants (i.e., clover and alfalfa) and crops for export such as cotton, sugarcane, sunflower, and citrus [6,7]. The most important crops in the winter season are wheat, broad beans, onions, and alfalfa, whereas irrigated rice,maize, and cotton are the main crops in the summer season. However, the lack of arable land, the constantly increasing scarcity of water (which is likely to be worsened due to the construction of the Grand Ethiopian Renaissance Dam at the Blue Nile River in Ethiopia), and the high population growth rate, combined with land degradation, impacts of climate change, and rural poverty, are massively challenging the agricultural sector. Additionally, high production costs, poor irrigation infrastructure, and land fragmentations negatively impact production, particularly that of smallholders. Faced with these challenges, for many smallholders, especially the younger generation, agriculture is not attractive any longer. Many smallholders migrate to urban centers. All in all, Egypt's agricultural sector cannot meet the growing and changing demands, and the country heavily depends on the import of food, mainly wheat [8].

Wheat is historically the most important crop in Egypt. Egyptians derive one-third of their daily caloric intake and 45% of their protein intake from wheat-based food,mainly in the form of subsidized bread *baladi* [1]. Egypt consumes the equivalent of 18.5 million tons of wheat per year, while the per capita share reaches 196 kg per year [8]. The annual per capita consumption of wheat exceeds the global average by more than 100 kg. In 1977, hundreds of thousands of Egyptians were protesting after the president announced a cut of subsidies on bread and other essential commodities. About 77 people were killed and a large number were injured in these Egyptian "bread riots" [9]. In January 2011, during the Egyptian revolution, the repetitive cheers were "Bread, freedom and social justice", in which bread was the first need. The availability and quality of bread *baladi* were some of the main reasons for the Egyptian revolution in 2011 [10]. All in all, wheat is historically a strategic and highly political commodity in Egypt, and the subsidizedbread prices have been unchanged for decades. The government stated the priceof the bread *baladi* at a subsidized fixed price of EGP 0.05 per loaf (equivalent to USD 0.01 in January 2022), which is less than one-tenth of the actual production costs [11]. Over the years, the bread subsidy program has become a massive economic burden on the Egyptian state budget. For instance, in the fiscal year 2019/20 only, the government allocated EGP 89 billion (USD 5.69 billion) for food subsidies, and more than half of this went to subsidized bread. In the 2020/21 fiscal year, bread and food subsidies amounted to EGP 84.5 billion (USD 5.4 billion) [12]. The government directly subsidizes every level of the bread value chain from wheat procurement to flour milling to bakery production to maintain thefinal consumer price at 0.05 EGP per loaf [13].

The subsidies mainly aim to targetand satisfy (poor and urban) consumers and not (poor and rural) producers. Despite the overall importance of wheat smallholders in Egypt, their situational and productional needs are largely neglected. Egypt is the world's largest wheat- importing nation. Only less than half of the national consumption can be met by domestic production; the rest has to be covered by imports [14]. In 2018, about 12 million tons of wheat were imported [15]. In 2021, Russia and Ukraine contributed 85% of the total wheat imports to Egypt (60–66% depending on the years from the Russian Federation and 20–25% depending on years from Ukraine) [16], followed by Romania, France, and the United States [16]. The annual value of wheat imports was highest in 2014 at USD 5.9 billion and lowest in 2013 and 2016 at USD 2.6 billion [17]. Global food prices and specifically wheat prices have been rising since 2020 as the result of the global supply chain disruptions caused by the COVID-19 pandemic. For instance, wheat prices averaged USD 280 per metric ton during the first half of 2021 and reached USD 317 per metric ton by November 2021. They were as high as around USD 500 per metric ton in February–April 2022 and will keep increasing because of the Russian-Ukrainian war [17]. Additionally, about 61% of the Egyptian population (63.5 million people) rely on subsidized *baladi* bread under a state-subsidized food card system [17]. The Egyptian government considered several measures aimed to fix the subsidized bread price at EGP 0.05 per and minimize its costs. Lastly, the government reduced the size of loaf from 110 g to 90 g, which is nearly 20%ofits actual size, and excluded approximately 7.5 million people (about 10.6% of thewhole population) from the subsidized food card system on the grounds that they can afford market prices [17]. The Egyptian government is seeking to apply new approaches to increase the quantities of flour extracted from domestic and imported wheat. For instance, the country is examining ways to obtain more flour from wheat grain by raising the extraction percentage for flour used for subsidizedbread to 87.5 percent instead of 82 percent. Egypt also studied mixing barley withwheat to produce *baladi* bread [18]. However, barley production was insufficient as the crop is used extensively in beverages. More recently, another method was tested by mixing potatoes and wheat in a 50–50 mixture [18]. Against this backdrop, the vision of substituting very costly and increasingly insecure wheat imports by increasing domestic production was outlined by the Government of Egypt in 2014 in the “Egypt Sustainable Development Strategy Towards 2030”.

The strategy vision 2030 aims to increase domestic local production and sets goals to expand the cultivation of wheat. It includes vertical expansion to maximizeproductivity per unit and relies mainly on using new varieties of wheat with high productivity and implementing modern irrigation methods to minimize water consumption, and on the other hand, implementing horizontal expansion by cultivating new lands and using suitable varieties of wheat for the nature of these lands that can adapt to its climatic conditions, salinity, and drought [14]. The vision of the 2030 document emphasized the government's aspiration to attain 74% wheat self-sufficiency by 2017. However, the actual self-sufficiency ratio in 2017 was 43% [14]. Given the Russian-Ukrainian war and other international crises, the wheat import substitution strategy has gained further importance, and the global wheat market faces significant challenges for the future wheat supply, as the two countries account for about 30% of the world's wheat supply. Russia is the largest wheat exporter and Ukraine is among the largest producers.

The aim of this study is to estimate the degree and trends of wheat self-sufficiency, the area of production, and the productivity in Egypt between 2000 and 2020 and to determine the concerning external pressures and system-immanent drivers in order to achieve wheat self-sufficiency in a sustainable way. At first, a descriptive method was used to determine the levels and trends of the wheat self-sufficiency ratio, the cultivated area of wheat, and its production and productivity between 2000 and 2020 based on official and unpublished data collected from the EgyptianMinistry of Agriculture and Land Reclamation (MALR) and the Central Agency for Public Mobilization and Statistics (CAPMAS). Additionally, a content analysis of published data in the forms of reviewed literature, published national and international surveys and reports, regulatory documents, grey literature, and journal articles published over roughly the past two decades was conducted.

2. Material and Methods

This study mainly relies on quantitative and qualitative data based on various published and unpublished sources, mainly from the Egyptian Ministry of Agriculture and Land Reclamation (MALR) and the Central Agency for Public Mobilization and Statistics (CAPMAS), the United States Department of Agriculture (USDA), the Food and Agriculture Organization of the United Nations (FAO), and the World Bank. In addition, a content analysis of national and international surveys and reports, regulatory documents, grey literature, and journal articles published over roughly the past two decades was conducted. The data were analyzed using descriptive statistics. Frequency counts, percentages, and means were used to describe the trends and prospects of wheat self- sufficiency, production, and yield.

3. Results

3.1Wheat Demands and Consumption

Wheat demand and consumption depend on wheat price, consumers' income, prices of substitutes (e.g., barley, rice, and maize), and population growth [19]. The increasing population puts pressure on wheat demand and consumption, which directly contributes to various food vulnerability problems in Egypt. The population growth rate is faster than that of domestic wheat production in Egypt, which exerts pressure on wheat consumption. The Egyptian population in 2020 was estimated at 100 million and consumed about 20 million metric tons of wheat in the same year [20]. The Egyptian population is forecasted to reach 140 million by 2050, which will require about 30 million metric tons of wheat [19]. Furthermore, the annual wheat consumption per capita in Egypt is estimated at 196 kg annually, which is about 3 times more than the average global consumption per capita, which is estimated at 66.9 kg annually, and more than 3 times the average per capita consumption in developing countries, which estimated at 60.5 kg annually [8].

At the same time, one-third of the Egyptian population lives below the poverty line(with less than $1.97 per person a day), which has a significant role in increasing wheat demand [19]. The wheat gap between 2000 and 2020 increased annually by 6.5%, which is equivalent to 538 thousand tons annually [21] (Figure 1). The increasing wheat gap puts pressure on wheat imports, which causes food insecurity, especially when international wheat prices spike, and the global supplychain is disturbed under different circumstances such as COVID-19 and the Russian-Ukrainian war. The average wheat gap in the period between 2000 and 2020 is estimated at 7715 thousand tons. The gap has ranged between a maximum gap in 2019 estimated at 12,936 thousand tons and a minimum gap estimated at 3564 thousand tons in 2001. The largest increase in the wheat gap was in 2010, with an estimated gap of 10,516 thousand tons from 6777 thousand tons in 2019, with a significant increase estimated at 3739 thousand tons. The lowest decrease in the wheat gap occurs in 2012, with a decrease in the wheat gap from 8782 thousand tons in 2011 to 6861 thousand tons in 2011, with an estimated gap of 1921 thousand tons.

3.2Wheat Self-Sufficiency (2000–2020)

Despite the almost linear increase in the total wheat production in Egypt between 2000 and 2020, with an annual average of 1.64% and an annual growth average of productivity estimated at a rate of 1%, the wheat self-sufficiency rate shows an average declination from 2001 to 2020 of 2% annually (Figure 2). The maximum and minimum ratios of wheat self-sufficiency were 64% in 2001 and 40% in 2019.The largest decline in self-sufficiency occurred in 2010, being 27% lower than in 2009 by an estimated decline of 0.76 ton/ha. The highest increase in wheat self- sufficiency was 20% in 2011 with an estimated rise of 0.85 ton/ha from 5.69 ton/hain 2010 to 6.54 ton/ha in 2011. The wheat self-sufficiency ratio is calculated as the percentage of domestic production from the total wheat supply total supply [12].

$$SSR = Production/(Production + imports - exports) \times 100$$

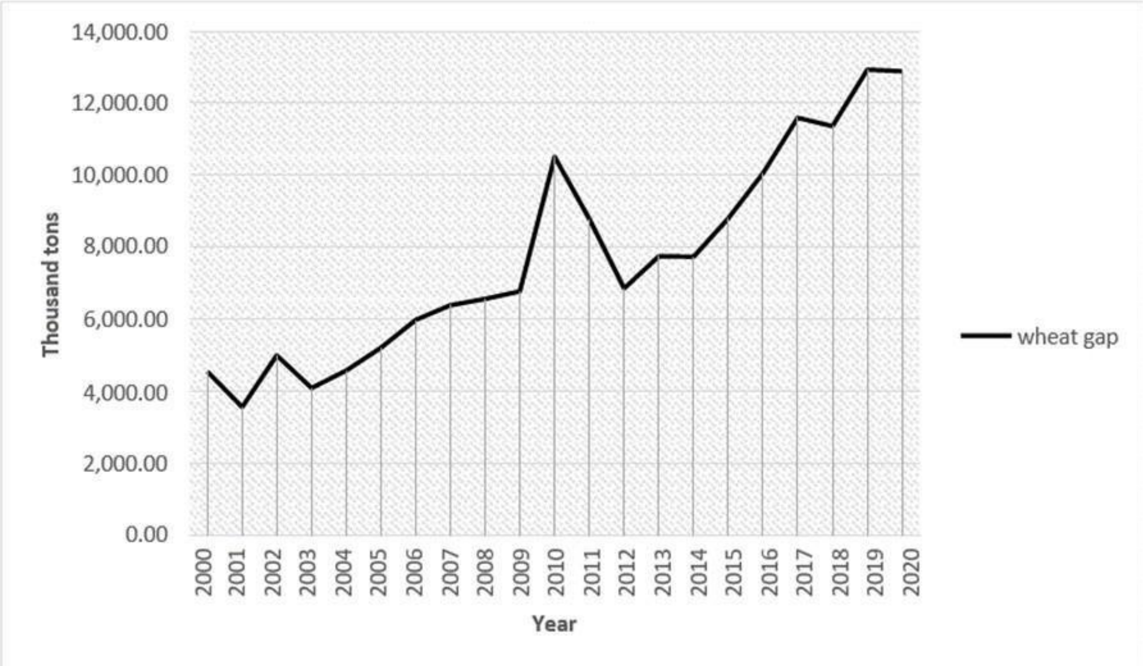

Figure 1. Trends of wheat gap in Egypt. Annual average percentage growth rate (2000–2020). Source: MALR & CAPMAS in Egypt and own elaboration [22,23].

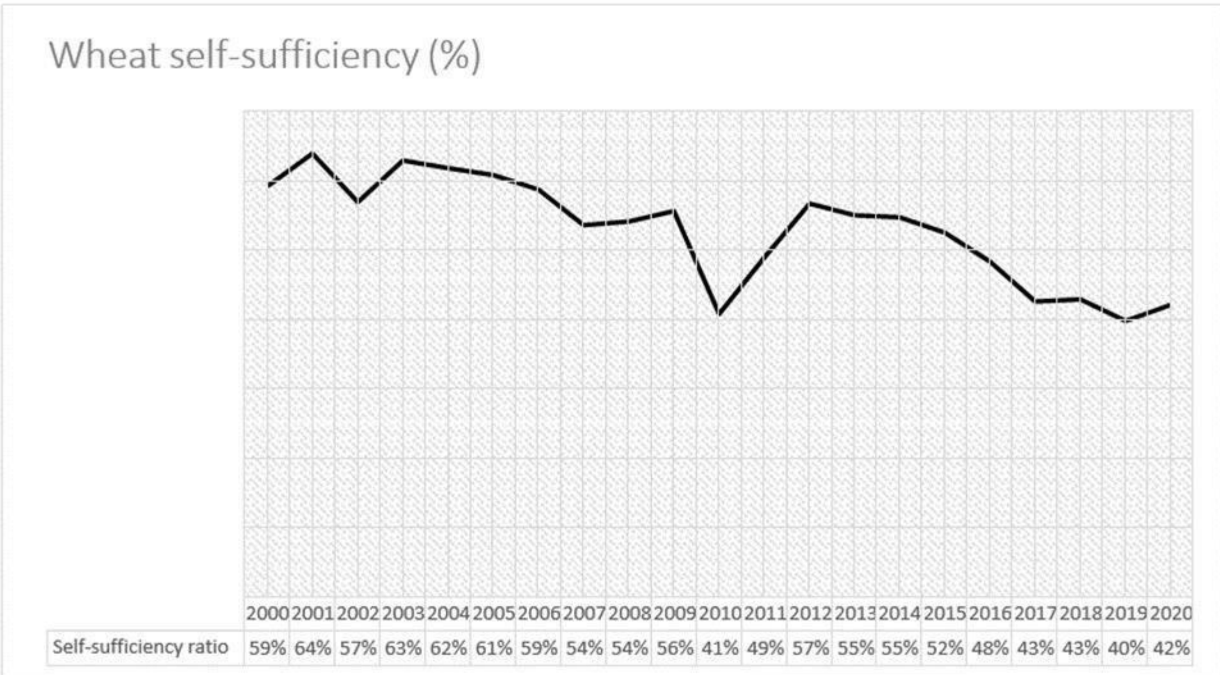

Figure 2. Trends of wheat self-sufficiency in Egypt. Annual average percentage growth rate (2000–2020). Source: MALR & CAPMAS in Egypt and own elaboration [22,23].

3.3Wheat Production (2000–2020)

The total wheat production in Egypt between 2000 and 2020 has an average of 8.032 million tons with a 1.64% annual growth rate (Figure 3). The maximum total production was in 2015 at 9608 thousand tons, and the minimum production was in 2001 at 6255 thousand tons. The data show a decline in total production between 2016 and 2019 with an annual average decline rate of 3%. The total production decreased from 9607 thousand tons in 2015 to 8558 thousand tons in 2019. In contrast, the total wheat production rose rapidly from 2001 (6254 thousand tons) to 2006 (8274 thousand tons), with an average growth rate of 5%.

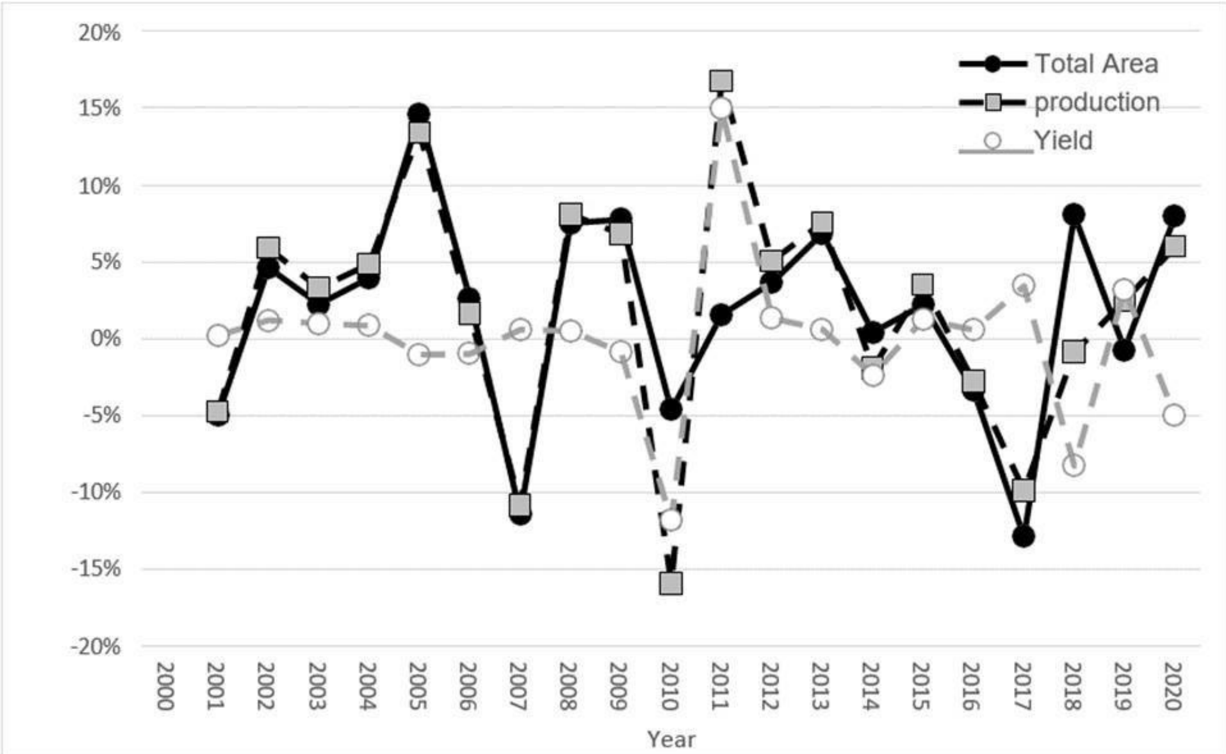

Figure 3. Trends in the total cultivated wheat area, wheat production, and yield ofwheat in Egypt. Source: MALR & CAPMAS in Egypt and own elaboration. Annual average percentage growth rate (2000–2020) [22,23].

Meanwhile, the total production rose from 6254 thousand tons in 2001 to 8274 thou- sand tons in 2006, with an increase of 2020 thousand tons. The highest increases in total production were in 2005 (with 13% more than in 2014) and in 2011 (with 17% more than in 2010). In turn, the highest decreases were in 2007 (11% lower than in 2006) and in 2010 (16% lower than in 2009). Despite the increase in the total wheat area in 2018 by 8% more than in 2017, the yield declined by 6%, and consequently, the total production declined by 1%.

3.4 Wheat Cultivated Area (2000–2020)

The total cultivated wheat area in Egypt grew between 2000 and 2020 by 1.54% annually (Figure 3). The largest areas were cultivated in 2015 with 1456 thousandhectares and the smallest cultivated wheat area was in 2001 with 983 thousand hectares. The largest increases were in 2005 when the total wheat area grew by 21% from 1094 thousand hectares in 2004 to 1253 thousand hectares in 2005, followed by another increase in 2015 with an increase of 16% compared with 2014. In contrast, the total wheat area declined between 2015 and 2019, with a significant drop in 2017 (20% lower than in 2016).

3.5 Wheat Yield (2000–2020)

The average yield in Egypt between 2000 and 2020 per hectare is 6.47 tons/ha, with an annual growth rate of 0.2% (Figure 3). The maximum yield of 6.86 tons/hawas harvested in 2017 and the minimum yield of 5.69 ton/ha was harvested in 2010. The data show significant drops in yield/ha in 2010 and 2018. The significant drop in yield was in 2010 with a declination of 0.75 tons per hectare, followed by a yield spike in 2011 with an estimated increase of 0.85 tons per hectare. A notable declination occurred in the period between 2017 and 2020, with a declination of 0.26 tons/ha (from 6.86 tons/ha in 2017 to 6.6 tons/ha in 2020).

3.6 Wheat Prices and Costs (2000–2020)

The price of domestic wheat supplied to the public silos in Egypt between 2000 and 2020 (EGP) increased annually by 71 EGP/ton (USD 4.5 in 2020), which is equivalent to 324 EGP/ha (USD 20.5 in 2020). In contrast, the total production costs increased by an average of 526 EGP/ha annually (USD 33.4 in 2022), whilethe maximum production costs were estimated at 27,710 EGP/ha in 2020 (USD 1755 in 2020). The lowest production costs were observed in 2005 with 7075 EGP/ha (USD 448). Between 2015 (10,905 EGP/ha (USD 1424) and 2020 (EGP 27,710 EGP/ha (USD 1755), the total production costs increased by 154%.

4. Discussion

The results reveal that the total wheat production in Egypt between 2000 and 2020 grew with an average growth rate of 1.64%, and the total wheat cultivated area grew in the same period with an average annual growth rate of 1.54%. In contrast, the wheat gap grew annually by an average growth rate of 6.5%, and wheat self- sufficiency grew by a 2% annual growth rate in the same period. The rapid population growth of 1.94% annually can be considered the main pressure on wheat self-sufficiency in Egypt. There are about 2 million more people every year and 392 thousand tons of additional wheat are needed annually, given an annual average consumption of 196 kg per capita. Despite the fact that the lowest total wheat production estimated at 6254 thousand tons and the smallest wheat cultivated area estimated at 983 thousand hectares between 2000 and 2020 was in 2001, the highest wheat self-sufficiency of 64% occurred in the same year. In 2019, Egypt had the lowest self-sufficiency rate of 40%, although with a total production of 8558 thousand tons on a total cultivated area of 1316 thousand hectares.

Figure 4 illustrates the total production of wheat in Egypt. The production started to rapidly rise from 2004 to 2005 as a result of the wheat self-sufficiency strategy implemented by the Minister of Agriculture and Land Reclamation at this time, Mr.Ahmed El-Lithy [15]. The strategy encouraged smallholders to grow more wheat by providing free machinery for land preparation and subsidized inputs such as seeds of high-yielding varieties [15]. The strategy also comprised strengthening agricultural extension. In combination, this resulted in a growth of total wheat areaof 15% and the lowest total production costs estimated at EGP 7075 per hectare between 2000 and 2020. In 2005, the Egyptian government partially removed thesubsidies for wheat growers, and new financial incentives for growing cash crops for export purposes were put in place. This reversed the so far positive trends in wheat production [15]. Wheat smallholders increasingly lacked access to machinery, agricultural services were reduced, and many production inputs were no longer subsidized. This led in 2007 to a significant drop of 11% in the wheat cultivated area and, consequently, to a significant drop in the total wheat production of 12%.

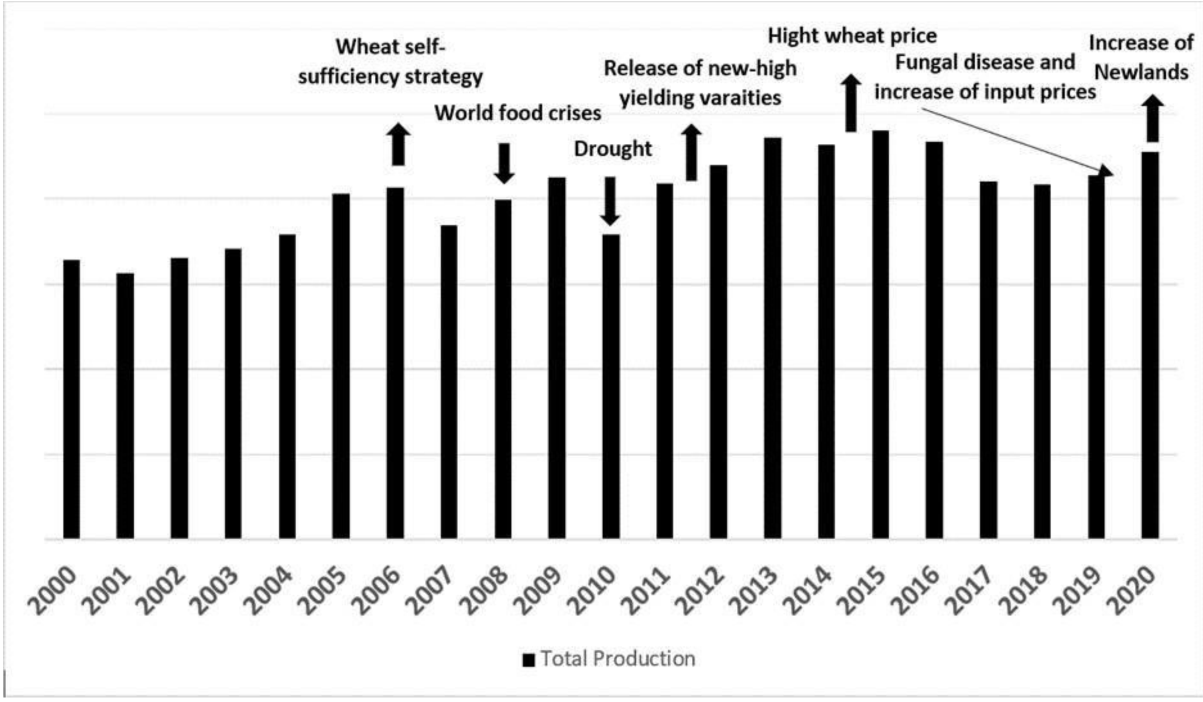

Figure 4. Trends and chronology of events that affected total wheat production inEgypt. (2000–2020). Source: MALR & CAPMAS in Egypt and own elaboration [22,23].

The world food crisis in 2007 led to a significant increase in international wheat prices. In Egypt, the food price spike led to demonstrations and violent conflicts that started in the industrial town of Mahalla, then spreading to other parts of the country [15]. This crisis refueled long-established arguments about the inefficiency of the government's food subsidy program at that time. The program relies in part on imported wheat and questions the government's ability to achieve wheat self- sufficiency [24]. In response to the crisis, the Egyptian government increased the national supply prices for wheat to encourage farmers to supply the increased amount of wheat to the national silos [8].

As direct result, the total production in Egypt increased in 2008 by 8%. In 2009, the farm-gate price of wheat declined again by 37%, which, together with an extreme heat wave in 2010, again led to a drop in the total production of 16% in 2010 and, in addition, led to significant drop in yield of 12% in the same year [25].

Figure 4. Trends and chronology of events that affected total wheat production in Egypt. (2000–2020). Source: MALR & CAPMAS in Egypt and own elaboration [22,23]. In 2010, the Egyptian government implemented the same policies as in 2007 and increased the wheat supply prices to encourage farmers to supply morewheat. This was subsequent to a decision of the Russian government to ban wheat exports to Egypt after millions of hectares withered in Russia due to drought and fires [15]. The resulting increase in global wheat prices led to a shortage of *baladi* in the Egyptian domestic market and, together with the lower quality, sparked new riots in Egypt in 2011 [10].

In 2016, the Egyptian government initiated an economic reform program that reduced parts of its energy subsidies, resulting in a significant increase in energy prices. Consequently, the production costs for wheat increased in 2017 by 34% compared with 2015 [21]. This led to a decline in the total cultivated wheat area of13% and a 10% reduction in the total production. In 2018, despite the increase in the total cultivated area of 8% compared with 2017, the total production declined again by 1%, and the yield declined by 6%, largely due to wheat rust infections and the storm known in Egypt as “Dragon Storm” [25]. The time-series data analysis shows the main external pressures and system-immanent drivers that impacted wheat area, yield, and total wheat production in Egypt between 2000 and 2020. The rapid population growth together with the high poverty levels significantly increased bread demands. National agricultural policies tried to increase domestic wheat production by supporting wheat growers in the forms of subsidized inputs, suitable prices and extension services, and high-yield varieties, but policies were changed very often, sometimes from year to year, and rather half-heartedly implemented. International markets as well as climate conditions and diseases played another critical role.

One major factor influencing the total wheat cultivated area in Egypt is the time of declaration of the domestic wheat supply price (at the public silos gate). The Egyptian Ministry of Agriculture government often declares the domestic wheat price as late as the end of the growing season [15]. If the price is relatively high, this will encourage farmers to use more of their land for wheat production in the coming season; thus, the total cultivated area will increase. Therefore, producers'decisions are often determined in the short term based on the previous year's price. In fact, the largest share of the governmental budget for wheat subsidies is applied to bread production along the supply chain, from flour milling to bakeries [8]. In addition, there is a substantial black market for wheat and flour, and in combination with corruption, part of the subsidized flour is sold on the black market, and other parts of wheat intended for human consumption end up as animal feed [26].

The prices that producers gain for their wheat produce compared with the production costs and the uncertainty due to the late declaration of the prices for the next season discourage many farmers from maintaining or even increasing their wheat production area or investing in higher productivity. According to the Global Food Security Index, Egypt ranks 62nd out of 113 countries worldwide.

Despite the Egyptian Sustainable Agriculture Strategy 2030 aiming at increasing productivity in the "old lands", the Egyptian government has been focusing in the last decades on the expansion of agricultural land into "new lands" through a "horizontal approach". For instance, between 2013 and 2022, the Egyptian government reclaimed 168.000 hectares in different land opening projects such as the "Four Million Acres Development Project", the "Northwest Coast Development Project", and the "West Minya Project" [27]. Yields in the "old lands"are mostly higher than those in the "new lands". Based on data from the MALR, the average wheat yields in the "old lands" is 6.68 t/ha compared with the maximum yield in the "new lands", which is 6.26 t/ha (see Figure 4). Moreover, developing "new lands" is protracted, very costly, and water-intensive, and the production process requires more fertilizers and other inputs compared with the "old lands" [28]. Wheat in the "new lands" is most often produced on larger farms by companies with contract workers, whereas wheat production in the "old lands" is almost entirely performed by smallholders [22,23,28].

Access to labor in the “new lands” is, however, difficult as they are often located in remote desert areas.Thus, the production costs are considerably higher while productivity is lower [29]. Consequently, producers in the “new lands” tend to grow cash crops for export instead of food crops such as wheat for domestic needs.

Egypt largely depends on importing wheat from Russia and Ukraine. Based on the official data from the Egyptian Ministry of Agriculture and Land Reclamation (MARL) and The Central Agency for Public Mobilization and Statistics (CAPMAS), in 2020, Egypt imported about 12.5 million tons of wheat. As a result of Russia’s invasion of Ukraine in February 2022, Egypt lost its main sources of wheat. In reaction, in March 2022, the Egyptian government declared a new national strategy aimed to cope with this massive breakdown of its major wheat imports and the skyrocketing prices in the world market. The new strategy relies on increasing wheat self-sufficiency in Egypt by increasing the cultivated area and using more high-yield varieties on the one hand and finding new international wheat markets on the other [25]. However, the strategy does not mention what procedures should be taken and how this would practically help to strongly increase domestic wheat production in minimum time. It also does not say what incentives wheat-growing smallholders would receive to significantly increase their wheat production. Many of the policies in the wheat sector in Egypt are short- term and try to respond to immediate crises. What is basically lacking are overall concepts and the long-term implementation of these concepts that strengthen the national agri-food system’s competitiveness, inclusiveness, and economic and ecological sustainability to ensure long-term food security in the country. Conceptshave to provide incentives for smallholders, who are the backbone of food security in the country, to increase their wheat production and productivity and enable them to increase their income from wheat production. This would simultaneously reduce rural poverty and make agriculture more attractive to the next generation. To be effective and sustainable, the policies have to be more long-term oriented and, particularly, based upon the concrete needs of the wheat-producing smallholders,mainly in the “old lands”.

Concrete support should include: (1) providing wheat-growing small- holders with tailored technical support and knowledge through agricultural extension, (2) providing wheat-growing smallholders with subsidized inputs on time, (3) declaring the national wheat prices before the growing season, and (4) determining higher domestic prices for domestic wheat supply. All these procedures combined would encourage and enable millions of experienced wheat-growing smallholders to increase their wheat-cultivated area on their land and improve their productivity, which would directly lead to an increase in overall domestic wheat production. Additionally, given Egypt's very limited cropland and water resources, these measures would increase yields per unit in a "vertical approach", mainly in the "old lands", which can, however, go in parallel with a "horizontal approach" of reclaiming "new lands" for the production of other products, mainly for export.

5. Conclusions

With a population of about 104 million people [20], Egypt is the most populated country in the Arab world and the third most populated in Africa. Wheat is the mostimportant food crop for the Egyptian diet and considered a highly strategic and political commodity in Egypt. Egyptians derive one-third of their daily caloric intakeand 45% of their protein intake from wheat-based food, mainly in the form of the subsidized bread *baladi* [1]. Wheat is mainly produced by millions of smallholdersalong the River Nile and in the Nile delta. However, Egypt is the world's largest wheat-importing nation, with only less than half of the national consumption beingmet by domestic production. The social and political stability of Egypt depends onthe availability of wheat and cheap *baladi.* The lack of access to affordable bread was one of the main reasons for the Egyptian revolution in 2011 in which the repetitive cheers were "Bread, freedom and social justice". In 2014, the Government of Egypt outlined the vision of substituting costly and insecure wheatimports by increasing domestic production. This strategy further gained pivotal importance since the significant increase in world market prices for wheat spurredby the Russian-Ukrainian war.

Against this backdrop, this paper aimed to determine the external pressures impacting wheat production and potentially wheat self-sufficiency in Egypt by analyzing the historical trends between 2000 and 2020. The findings of the paper show that although Egypt's wheat yields per unit of land are one of the highest globally, wheat self-sufficiency, however, declined annually by two percent on average from 2000 to 2020. Wheat production directly competes with cash crops such as broad beans and clover in old land and citrus, vegetables, and trees in new land, which are often more expensive to produce due to limited arable lands and scarce water resources. Most wheat is produced by smallholders in the "old lands". Wheat production in Egypt is characterized by high fluctuations in cultivated area, production, and yields. Policies are frequently changing, and wheat producers perceived a constant and massive decrease in support from the government and extension services between 2000 and 2020. Wheat-growing smallholders have no incentives to increase their wheat production given the shortage of subsidized inputs, inappropriate wheat prices, climate change, diseases, and increasing input prices. All in all, the attractiveness of wheat production, especially for the younger generation, declined between 2000 and 2020. The development of new agricultural land in the reclaimed "new lands" did not help to substantially increase domestic wheat production. Consequently, imports of wheat to Egypt were increasing between 2000 and 2020 instead of decreasing, and self-sufficiency is further predicted to decline in the next decade [30,31]. As Egypt's population rapidly grows and cultivable areas and available water are predicted to decrease, the country's reliance on wheat imports is likely to increase. One alternative would be to enhance the ability and incentives of millions of wheat-growing smallholders in the "old lands" to enhance their productivity. Based on this study this would need: (1) providing wheat-growing smallholders with technical support and knowledge through agricultural extension, (2) providing wheat-growing smallholders with subsidized inputs on time, (3) declaring the national wheat prices before the growing season, and (4) determining higher prices for domestic wheat supply. In short, to increase domestic wheat production, there is a significant need to implement an effective and long-term sustainable agricultural policy that makes wheat production (more) attractive and feasible for smallholders again.

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Chapter 5

The Contribution of Agronomic Management to Sustainably Intensify Egypt's Wheat Production

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Abstract

In Egypt, recent shortfalls in the wheat supply from Russia and Ukraine have necessitated substantial increases in domestic production. As agricultural practices influence the yield of bread wheat, we assessed current production strategies in the wheat-based systems of Egypt and investigated their effects on wheat productivity infour study areas in the Nile Delta. We used a multi- stage random sampling technique to select 246 wheat-producing farmers and applied structured questionnaires to assess farming practices and crop performance attributes. Data were analyzed by using descriptive statistics, analysis of variances, and multiple regression models. Wheat farmers were on average 56 years old with about 30 years of farming experience. Land holdings were rather small, with an average of 1.05 hectares and a mean wheat yield of 6.4 metric tons (t)/hectare (ha). Farmers devote <20% of their cropland area to wheat. Of the large observed variation in wheat yield (4.2–8.5 t/ha), 59% was explained by differences in applied cropping practices in the multiple regression model. The application of mineral fertilizers was mostly inappropriate and unbalanced, with an overuse of nitrogen and phosphorus, the complete absence of potassium and micronutrient fertilizers, and insufficient rates of applied organic amendments. The type of the preceding summer crop and the irrigation frequency were found to be the most influencing factors, explaining 7.5% and 38% of the variation in wheat yields. The majority of farmers with low wheat yields irrigated their crops twice per season, while only 7% of high-yielding farmers applied the recommended irrigation frequency of >5 times per season. Most farmers had poor knowledge of modern agronomic practices and inadequate access to information. Toenhance domestic production in Egypt, there is a need for fiscal incentives, permitting or stimulating wheat-producing farmers to devote larger shares of their cropland to wheat cultivation. In addition, policies must enable wheat producers to improve their productivity by implementing adequate and sustainable agricultural practices such ascrop rotations, balanced mineral nutrient supply, and the use of organic amendments. However, the most important factors are interventions and technologies that improveprovision and increase the use efficiency of irrigation water.

Keywords: agronomic practices; fertilizers; food security; irrigation; Triticum *aestivum*

1. Introduction

Given that Egypt is an agricultural country, 53% of the population lives in rural areas, with livelihood directly or indirectly depending on agricultural activities. About 27% of the population is employed in agriculture, a sector contributing nearly 15% of the national income [1]. However, 97% of Egyptian land is desert. Out of the total land area of about 100 million hectares (ha), Egypt has a cultivated land area of only 3.6 million hectares (ha), of which, approximately 2.7 million hectares (ha) are concentrated in and around the Nile Delta [2]. There, crop farming is practiced on both the "old land" and the "new land". The "old land" is located along the Nile River and in the Delta region, extending from Giza in the South to El Manzala and Rashid in the North, covering about one million ha of arable land [2]. The area is characterized by heavy alluvial clay soils with high organic carbon content and a high water-holding capacity. Water supply to crops relies mainly on surface gravity irrigation. The "new land", on the other hand, has been reclaimed recently from the desert. Located west and east of the Delta and covering 0.88 million hectares (ha), the new land is characterized by sandy soils with low water-holding capacity and low soil fertility. Water for crops is provided by pressurized irrigation systems (sprinklers and pivot irrigation) [3]. Bread wheat (Triticum *aestivum L.*) is the most important crop in Egypt, occupying 1.5 million hectares (ha) [4] and representing nearly half of the total cultivated area during the winter season [5]. In addition, Egyptians derive 1/3 of their daily caloric intake and 45% of their protein intake from wheat-based food, mainly in the form of *baladi* bread. Egypt consumes the equivalent of 20 million metric tons (t) of wheat per year, and less than half of this amount is met from domestic production, the remaining share being covered by imports. In 2021, Russia and Ukraine contributed 85% of the total wheat imports to Egypt (60–66% from Russia and 20– 25% from Ukraine) [6]. Wheat prices in Egypt increased by 100% between June 2021 and April 2022 [6], with the largest increases occurring at the beginning of the Russia–Ukraine war in February 2022 and contributing to the national inflation record high of 20% in March 2022 [7]. With recently soaring wheat prices on international markets, the annual cost for wheat imports into Egypt is expected to further increase in 2023, thus creating a significant burden on the Egyptian economy. To mitigate the risk of bread shortages and potential social unrest resulting from abrupt increases in the price of bread, Egypt must take steps to reduce its reliance on imports of wheat from Russia and Ukraine. This can be achieved through the exploration of alternative sources of international wheat and,more importantly, by enhancing domestic wheat production [8]. The government of Egypt has already outlined the vision of increasing domestic wheat production in the “Egypt Sustainable Development Strategy Towards 2030” in 2014. The document emphasized the government's aspiration to attain 74% wheat self- sufficiency by 2017. However, self-sufficiency in 2017 reached only 43%.

The increasing gap between domestic wheat production and consumption has been mainly the result of drivers outside of the sphere of agricultural production. Thus, the rapid population growth rate, policies to subsidize the price of bread while withdrawing subsidies for farm inputs, late declarations of prices by the government, and changing climate conditions acted as external pressures, increasing wheat demand while disincentivizing domestic production. Agriculture system-immanent responses of small-scale wheat producers included devoting larger shares of the wheat harvest to home consumption and for feeding animals instead of selling it to the government for filling the storage silos. Additionally, the low productivity of domestically produced wheat incentivizes farmers to reduce the area cultivated with wheat and to substitute wheat in the crop portfolio with other, more economically competitive crops, such as clover and broad beans [6].

In the past, Egypt compensated for low domestic production by increasing wheat imports; however, this compensation was at the cost of declining food self- sufficiency. With recent disruptions in wheat supply from Russia and Ukraine, andskyrocketing prices for wheat and agrochemicals on international markets, there is an urgent need to strengthen domestic production by increasing cultivation and intensifying production practices. The latter entails balancing the application of external inputs and enhancing the efficiency of scarce water resources. Considering the large gap between potential wheat yields of over 10 t/ha [9] and farmers' actual yields of about 6 t/ha [5], it is apparent that production increases are achievable. The focal target area for such production gains is the Nile Delta, with its fertile soils and adequate access to irrigation water. This is particularly thecase for El Beheira Governorate, where 65% of the wheat in Egypt is currently produced [10].

There is little knowledge regarding the status quo of current production strategies and of the performance attributes of wheat-based systems in relation to the on- farm resource endowment of wheat producers (availability of land, labor, and capital). We surmise that farmers' adaptive capacity to respond in a timely manner to changing demands is related to their access to modern technologies and extension services, as well as to the availability and use of human capital [11].

The main objective of this study was to investigate current production practices and identify key constraints affecting wheat productivity in smallholder farms in El Beheira Governorate, which is located in the Nile Delta of Egypt. We combined structured inter- views, field observations, and transect walks to collect data from 246 smallholder wheat farms in the study area. Specifically, we aimed to:

1. identify the current production practices used by smallholder wheat farmers in the study area, including cultivation methods, and water management;

2. identify the key constraints affecting wheat productivity in smallholder farms, both as perceived by farmers and as observed by researchers, including issues related to soil management, access to inputs and markets, and labor availability;

3. relate crop performance attributes, such as yield, to the identified constraints affecting wheat productivity;

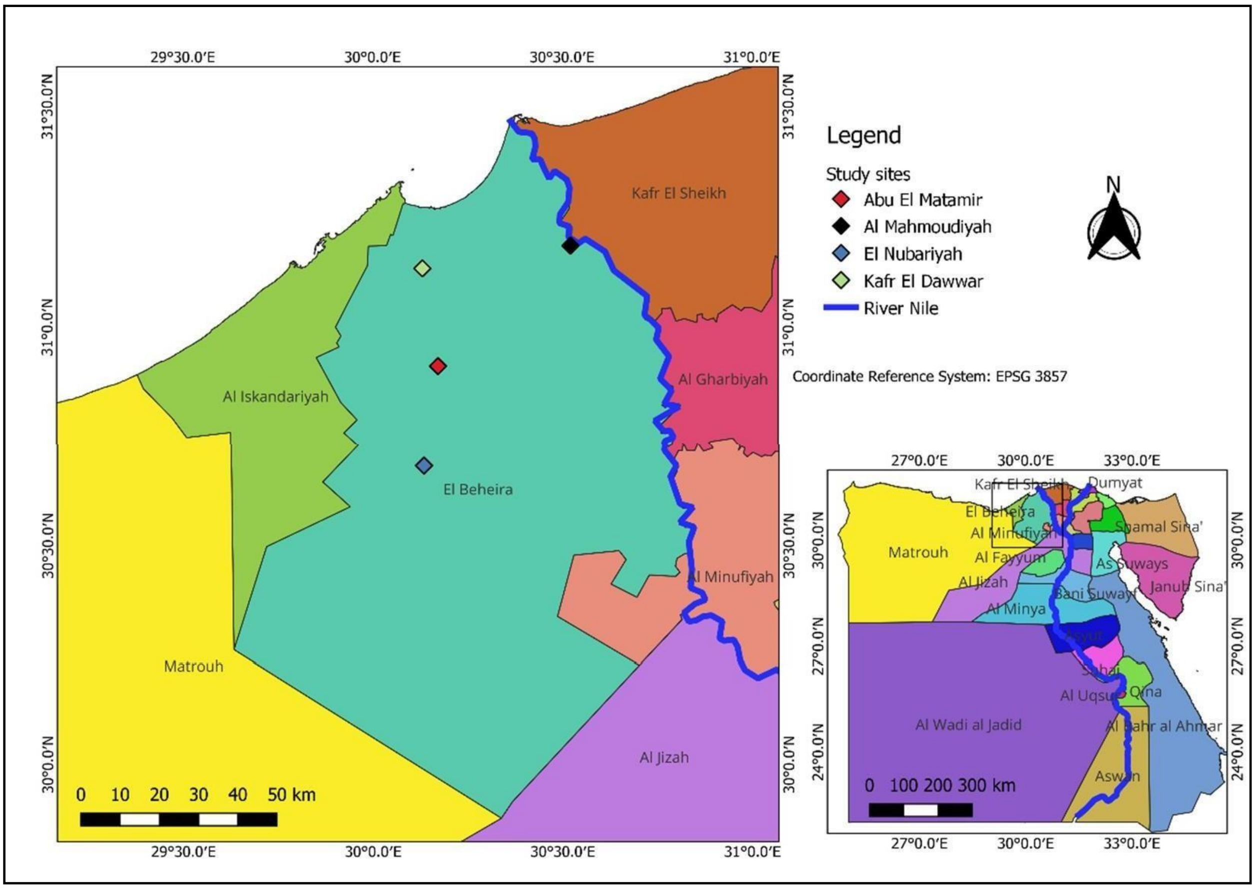
outline the necessary actions to develop yield-gap-reducing production strategies that can be targeted to smallholder wheat farms in the study area and to guide policymakers and stakeholders in developing targeted interventions and policies that promote sustainable wheat production in Egypt. Overall, the goal of this study was to provide insights into the current state of wheat production in smallholder farms in El Beheira Governorate and to provide recommendations forimproving productivity and sustainability in this important sector.

2. Methods

2.1 Description of the Study Area

Approximately 57% of the land used for wheat cultivation in Egypt is located in the Nile Delta [12]. We selected El Beheira Governorate in the North-West of the Nile Delta (30◦36′36″ N, 30◦25′48″ E) as the key study area since it is the wheat basket of Egypt, where millions of smallholders cultivate wheat with production methods similar to those in other wheat-growing areas in Egypt. El Beheira Governorate covers 9826 km2 west of the Rosetta branch of the river Nile. It is densely populated with approximately 7 million people, of which more than 70% work in agriculture. Four highways connect El Beheira to the central markets of Cairo andAlexandria. It consists of 13 centers, 14 cities, 84 rural municipalities, and 407 villages [8].

While representing only 15% of the total agricultural land area of Egypt [13], El Beheira Governorate produces 60–65% of the total wheat of the country. Wheat is grown in rotation with irrigated summer crops on relatively small land holdings in the peri-urban fringes of the "old land", and with pivot and overhead sprinkler irrigation in fallow rotation systems on large land holdings in rural areas of the "new land" [14]. Within El Beheira Governorate, four municipal divisions were selected as the main study areas, based on differences in water availability, market access, and soil type. They comprised (1) Al Mahmoudiya Division, consisting of 14 villages located on the Rosetta branch of the Nile (rural–moist scenario); (2) Kafr El Dawar Division, consisting of 31 villages located along major highways with good market access (urban–moist scenario); (3) Abu El Matamir Division, consisting of 24 villages located on the desert margin (rural–dry scenario); and (4) El Nubariyah Division, representing the cultivated desert (urban–dry scenario) (Map 1).



Map 1. Study locations (municipal divisions) within El Beheira Governate in Northern Egypt.

2.2 Data Collection

We identified 246 wheat growers by random selection from official documents from the official units of the Ministry of Agriculture and Land Reclamation in each study area (MALR), listing all wheat-growing households of each village. The number of wheat growers selected in each municipal division was proportional to the respective farmer populations. The number of participants was deemed sufficient to achieve the desired level of statistical significance and precision (sufficient to obtain a 95% confidence interval with a margin of error of 5%) while also ensuring the feasibility of data collection within the timeline and resources of the study.

We systematically characterized and categorized prevailing production practices, the resource endowment of households, and wheat performance attributes during the wheat-cropping season of 2020/2021. We interviewed wheat-producing farmers by using structured questionnaires, which were divided into two sections: (1) farmer attributes and resource endowment, and (2) agronomic practices. The questionnaires were pre-tested with 25 farmers in all 4 study areas. The survey part on agronomic practices included questions on crop rotations, seed sources, soil tillage, crop establishment, mineral and organic fertilizer use, number of irrigation events applied, weed and pest control strategies, harvesting methods, and produce uses (sale vs. home consumption).

2.3 Data Analysis

Descriptive statistics analyzed the primary data. Frequency counts, percentages, and means described the socio-economic characteristics of the survey respondents. We used two-way ANOVA to test for differences in agronomic practices and wheat yields.

We tested the response variable "Wheat yield" against 14 predictor variables to identify the main yield-affecting agronomic practices via multiple linear models [15]. The potentially yield-affecting variables comprised location and soil type; the preceding crop rotation; tillage method (manual, animal, mechanical) and tillage depth; seed source (market vs. self-grown) and seeding method and rate; application rates of farmyard manure; use and rates of mineral N, P, and K fertilizers; application of micronutrient fertilizers; and irrigation method (gravity vs.sprinkler) and frequency.

We excluded the parameter "location" for the site at El Nubariyah in the "new land"due to the limited sample size of only 9 respondents. The location variable was also excluded from the general analysis to avoid results being influenced by random errors in the data [16] but also due to the absence of significant effects onwheat yields across the four study areas (Figure 2). Finally, predictor variables with values of "0" (no variability in the data set) were not considered. These concerned the seeding method (all manual broadcast), the tillage depth, the use of K fertilizer, and the application of micronutrients.

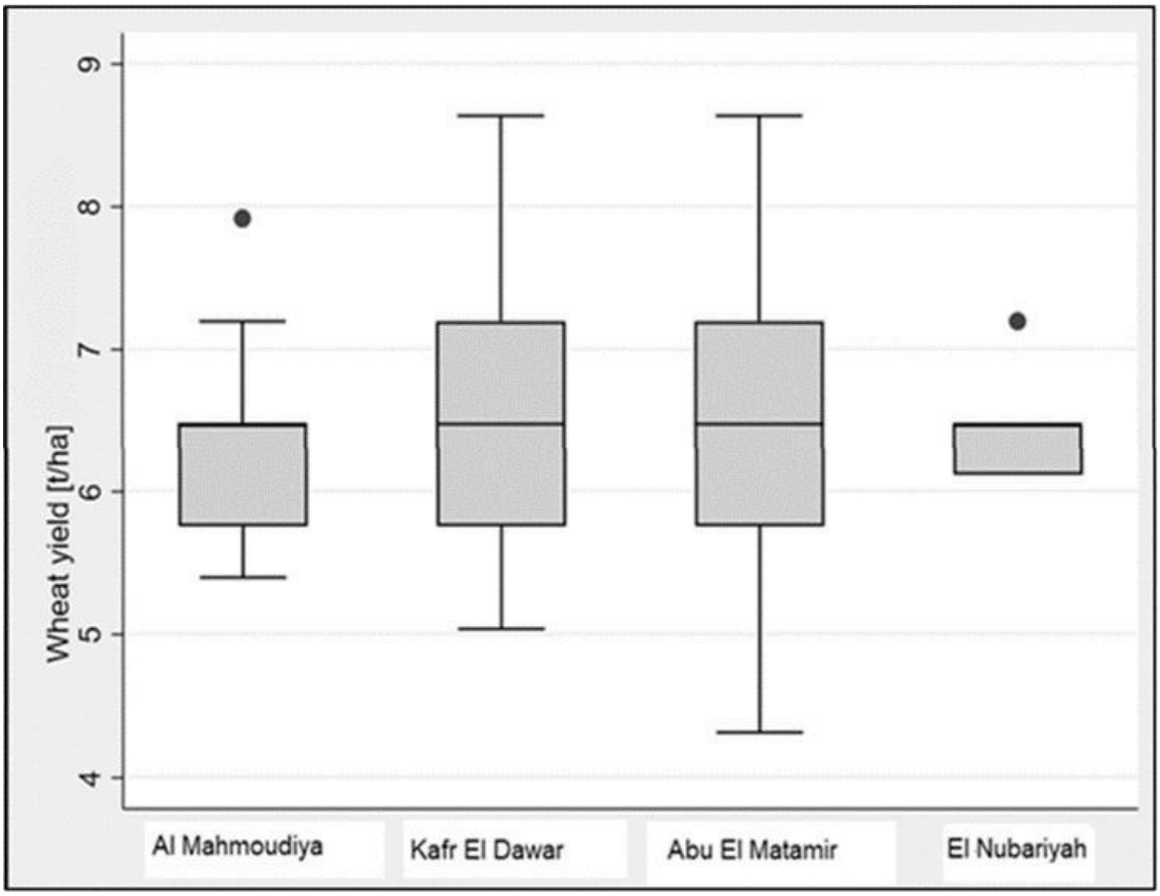


Figure 2. Wheat yield and yield variability in the four study areas in Egypt (survey2021/22).

The robust method identified outliers to minimize their effect on data estimates, variance, and errors across predictor variables [16]. To detect the multi- collinearity, we ensured that variance inflation factors (VIF) were <10 [15]. Cook's D method prevented "influential" value-distorting generalizations [17]. The normality of data distribution and the stability of regression coefficients were tested via bootstrap [18]. Finally, pairwise comparisons identified the effect of predictor variables on wheat yield [19,20].

3. Results

3.1 Farmer Attributes and Resource Endowment

Attributes of wheat-producing farmers and their endowment with production re- sources (land, labor, capital) strongly varied between farms. In our study, we employed proxy measures for actual capital investment such as the use of labor force, land size, and amount of fertilizer. Our findings revealed that land size had a significant and positive influence on wheat productivity, indicating that farmers with larger landholdings were able to produce greater amounts of wheat per hectare. Moreover, we found that the availability of labor had a positive impact on productivity, implying that farmers with greater access to labor were better able tomanage their crops. Furthermore, the results demonstrate that farmers with greater financial resources were able to invest in inputs such as fertilizers, which resulted in higher yields. Conversely, our statistical analysis indicates that there were no significant differences across farmer age and years of experience, and the variations in wheat yield. Farmers were middle-aged, with a mean age of 56 years (variation of 32–79 years), and with a mean experience in wheat cultivation of about 30 years. Moreover, the mean landholding size of 2.5 feddan (1.05 ha) varied greatly from 0.2 to 2.3 ha. The share of the land area occupied by wheat was 0.5 feddan, corresponding to 20% of their total landholdings, the remaining area was occupied by other winter crops, mainly by clover and broad beans. Wheat farmers depend largely on labor provided by family members and neighbors for tillage and fieldwork during the growing seasons. Improved varietiesof modern high-yield wheat are, in most cases, obtained from local units of the Ministry of Agriculture, and, in some cases, farmers use self-grown seeds from the previous harvest (Table 1).

Table 1. Key characteristics of wheat-growing smallholder farms (survey of 2020/21).

	Age of Farmer (Years)	Farming Experience (Years)	Farm Size (ha)	Wheat Yield (t/ha)
Mean	56	30	1.05	6.4
Range	47	40	2.1	4.2
Minimum	32	10	0.2	4.2
Maximum	79	50	2.3	8.5
Count (n)	246	246	246	246

Farmers receive mineral nitrogen fertilizers at subsidized prices from the local agricultural co-operatives, while other external inputs (e.g., agrochemicals) must be bought on private markets. Applied organic amendments concern mainly farmyard manure from farmers' own livestock. Most farmers have adequate access to machinery services for soil tillage and harvest. However, access to knowledge regarding modern production technologies and to agriculture extension services is very poor. Farmers use the largest share (65%) of their wheat production for home consumption (subsistence-orientation), while the wheat straw is fed to livestock. Only about one third (35%) of the whole grain production is commercialized and sold to intermediaries and wheat traders to be stored in government silos.

3.2 Wheat Yield and Agronomic Practices

The average yield of wheat in 2021 was 6.4 t/ha, with a minimum of 4.2 t/ha and a maximum of 8.5 t/ha and rather little variation between the study areas (Figure 2). Yields varied according to agronomic practices applied, with the largest variations, and, hence, the largest uncertainties in the outcome of investments, in the dry and strictly rural desert margin site at Abu El Matamir, and the least variation at sites with good access to irrigation water (Al Mahmoudiya in the "old land" and El Nubariyah in the "new land"). The rates of adoption of agronomic practices reflect farmers' adaptive capacity to changing conditions and for meeting their aspirations and expectations. They concern the type of crop rotation, seed sources, the mechanization of tillage and harvest operations, and the use of agrochemicals.

Wheat grows during the winter season (November to April) and is usually cultivated in rotation with (irrigated) summer crops. These summer crops differ by soil types. Thus, farmers cultivate maize and rice during the hot summer season on heavy clay soils in the divisions of El Mahmoudiyah and Kafr El Dawar, while maize and sunflowers dominate the summer crops on loam soils in Abo El Matamir, and peanuts, potatoes, and sesame dominate on the sandy soil of Nubaria divisions. These crops also differ in their field occupancy times, and the late harvest of long-duration crops can delay a timely establishment of the wheat crop. While the recommended time for wheat seeding in the study areas is mid- November, seeding times in the sample ranged from early November to late December. Delays in seeding are related to crop rotations (late harvest of the summer crop), the untimely availability of machinery services for soil tillage, low labor availability, and late provision of subsidized inputs (mainly mineral N) from agricultural cooperatives.

The application of organic amendments (mainly farmyard manure) and of mineral P fertilizers (where applicable) precedes soil tillage by tractors, while wheat is seeded by manual broadcasting. Mineral N fertilizers are usually split-applied, witha first dose received after seedling emergence and subsequent applications before irrigation events. None of the interviewed farmers applied potassium or micronutrient fertilizers. Water in the "old land" is applied via flood irrigation by using water pumps from canals, while overhead sprinkler irrigation dominates the water supply in the "new land". The number of irrigation events during the wheat- growing season differed by site and soil types, ranging from one to five applications on clay soils in the "old land" and five to nine applications on sandy soils in the "new land". The results of the multiple regression model that was employed to determine the effects of agronomic practices on wheat productivity show the high and significant value of the coefficients of multiple determination (R2) for the predictor variables "preceding summer crop", "wheat seeding rate", "manure amount", "irrigation frequency", "mineral N application rate", and "P fertilizer use" (Table 2). These variables explain 59% of the total observed variation in wheat yield in the model. The following paragraph dissects individual agronomic practices regarding their effectiveness in improving wheat yields.

Table 2. Multiple regression estimates of effects of agronomic practices on wheat yield in Egypt (survey of 2020/21).

Variable	Df	F Value	P > f
Preceding crop (category)	4	7.5	0.001
Seeding rate (kg/ha)	3	3.74	0.012
Manure amount (t/ha)	3	4.31	0.006
Irrigation frequency (#)	3	38.31	0.001
Mineral n rate (kg/ha)	4	2.68	0.033
Mineral p rate (kg/ha)	5	3.19	0.008
Denominator	212		

3.3 Individual Yield-Affecting Variables

3.3.1 Crop Rotation

The preceding crop variable refers to the crop rotation and to the summer crop that is cultivated before wheat. The crop cultivated in rotation with wheat significantly impacted wheat productivity at 5% probability, explaining >7% of the total variation in wheat yield (Table 3). The highest wheat yield of 6.7 t/ha (range: 6.1–7.3 t/ha) was observed when wheat was cultivated in rotation with potatoes. This was followed by maize, rice, sunflower, and sesame with mean productivitiesof 6.4, 6.2, 5.8, and 5.5 t/ha, respectively.

Table 3. Effect of different summer crops grown in rotation with wheat on grain yield response of wheat in Egypt (survey of 2020/21).

Preceding Summer Crop	Wheat Yield (t/ha)	Standard Error	T	P > t	[95% Conf. Interval]	
Rice	6.27 b	0.078	80.2	<0.001	6.11	6.42
Maize	6.44 ab	0.075	85.6	<0.001	6.30	6.59
Sesame	5.51 c	0.260	21.2	<0.001	5.00	6.03
Potatoes	6.73 a	0.301	22.3	<0.001	6.14	7.33
Sunflower	5.83 bc	0.184	31.6	<0.001	5.47	6.20

Different letters denote significant yield differences by Tukey Test (0.05).

3.3.2 Seeding Rate

The amount of wheat seeds that smallholder farmers broadcast in each season varied between 90 and 170 kg/ha. High seeding rates were not related to increased yields, and the variable "seeding rate" explains only <4% of the total variation in wheat yield (Table 4). Actually, smallholders obtained the highest wheat yields (6.6 t/ha) with the lowest seeding rates (95 kg/ha). However, most farmers (>52%) exceeded this amount, using on average 120 kg/ha.

Table 4. Effect of seeding rates on grain yield response of wheat in Egypt (survey 2020/21).

Seeding Rate (kg/ha)	Wheat Yield (t/ha)	Standard Error	T	P > t	[95% Conf. Int.]		Share (%)
>100	6.56 [a]	0.0780	83.25	<0.001	6.414	6.72	29.3
100–130	6.33 [ab]	0.0512	123.72	<0.001	6.23	6.44	52.0
130–150	6.43 [a]	0.0996	64.59	<0.001	6.23	6.63	17.9
<150	6.06 [b]	0.1421	42.65	<0.001	5.78	6.34	0.8

Different letters denote significant yield differences by Tukey Test (0.05).

3.3.3 Organic Amendments

Most smallholders apply farmyard manure as an organic fertilizer source. The amounts applied are positively and significantly related to "wheat productivity", ex- plaining 4% of the total variation in wheat yield (Table 1). Increasing application rates of farmyard manure can enhance soil fertility and soil water-holding capacityand were shown to increase wheat yields up to 6.7 t/ha with 20 t/ha of manure. However, such large amounts were used by only <12% of the farmers in the sample (Table 5).

Table 5. Effect of farmyard manure on grain yield response of wheat in Egypt (survey 2020/21).

Manure Applied (m^3/ha)	Wheat Yield (t/ha)	Standard Error	T	P > t	[95% Conf. Interval]		Share(%)
NONE	6.25 [b]	0.121	52.6	<0.001	6.11	6.58	14.2
8	6.27 [b]	0.070	89.5	<0.001	6.13	6.40	36.6
16	6.51 [ab]	0.072	90.2	<0.001	6.37	6.65	35.4
20	6.79 [a]	0.101	66.1	<0.001	6.49	6.89	11.8

Different letters denote significant yield differences by Tukey Test (0.05).

3.3.4 Irrigation Frequency

Exact amounts of applied irrigation water could not be assessed through the survey, and thus, we used the frequency of applied irrigation events as a proxy for water availability and crop supply. The number of irrigation events within one wheat-growing season was significantly related to total factor productivity, explaining 38% of the total variation in wheat yield (Table 6). The results reveal that 5 irrigation events or more during the wheat-growing season provide an average yield of 7.8 t/ha (range: 7.4–8.1 t/ha). However, the majority of wheat farmers (>59%) irrigate only twice per season, and only 7% apply 5 or more irrigation events.

Table 6. Effect of the number of irrigation events per season on the grain yield response of wheat in Egypt (survey 2020/21).

Irrigation Events	Wheat Yield (t/ha)	Standard Error	T	P > t	[95% Conf. Interval]		Share (%)
Once	5.82 [c]	0.1049	55.5	<0.001	5.62	6.03	18.3
Twice	6.36 [b]	0.0473	134.5	<0.001	6.26	6.45	58.5
3–4 times	6.81 [b]	0.1462	46.7	<0.001	6.53	7.10	12.6
≥5 times	7.83 [a]	0.1762	44.4	<0.001	7.48	8.17	6.9

Different letters denote significant yield differences by Tukey Test (0.05).

3.3.5 Mineral N Fertilizer

The rates of mineral fertilizer nitrogen (primarily in the form of ammonium nitrate) applied to wheat were very high, ranging from 200 to >580 kg N/ha. This figure represents an excess of the rates of N removed at the current grain yield levels of about 6 t/ha, corresponding to about 120 kg N/ha absorbed by the wheat crop. Consequently, no significant yield response to applied N rates was observed (over-supply with subsidized N fertilizer), and about one third of all farmers (34%) applied amounts in excess of 350 kg/ha (Table 7).

Table 7. Effect of different rates of applied mineral nitrogen on grain yield response of wheat (survey 2020/21).

N Application Rate (kg/ha)	Wheat Yield (t/ha)	Standard Error	T	P > t	[95% Conf. Int.]		Share (%)
>250	6.24 [ab]	0.091	68.05	<0.001	6.06	6.42	29.7
250–400	6.27 [ab]	0.077	81.97	<0.001	6.12	6.42	33.7
400–550	6.38 [a]	0.083	76.75	<0.001	6.22	6.54	23.9
<550	6.12 [b]	0.095	64.42	<0.001	5.93	6.30	12.6

Different letters denote significant yield differences by Tukey Test (0.05).

3.3.6 Mineral P Fertilizer

Mineral P fertilizers were usually applied as (P2O5) single-super-phosphate at rates of 100–300 kg P/ha. Similar to the corresponding rates for mineral N, these rates are by far in excess of the P demand of wheat, which, at the current wheat yields, rarely exceeds 15 kg P/ha. Thus, no clear yield response with increasing P application rates is apparent. The use of P fertilizer explains <3% of the total variation in wheat yield (ns), and the highest yields were obtained with the lowest P application rates (Table 8).

Table 8. Effect of different rates of mineral phosphate application on wheat yield response in Egypt (survey 2020/21).

P Application (kg/ha)	Wheat Yield (t/ha)	Standard Share Error	t	P > t	[95% Conf. Interval]		Share (%)
>150	6.64 [a]	0.121	54.7	<0.001	6.40	6.88	26.0
150–210	6.26 [b]	0.152	41.1	<0.001	5.96	6.56	10.2
210–260	6.27 [b]	0.056	110.2	<0.001	6.06	6.28	42.7
260–300	6.30 [ab]	0.134	47.7	<0.001	6.13	6.66	11.8
<300	6.34 [ab]	0.100	63.0	<0.001	6.14	6.54	9.4

Different letters denote significant yield differences by Tukey Test (0.05).

We can summarize that Egyptian wheat farmers are rather elderly and land- strapped, with little access to knowledge about intensified production technologies. Consequently, some (subsidized) inputs such as N and P fertilizers and improved wheat seeds are applied in excessive and non-yield-effective amounts. The type of crop rotation, the amount of applied farmyard manure, and the number of irrigation events are the most yield-effective agronomic practices that warrant more future attention (Figure 3).

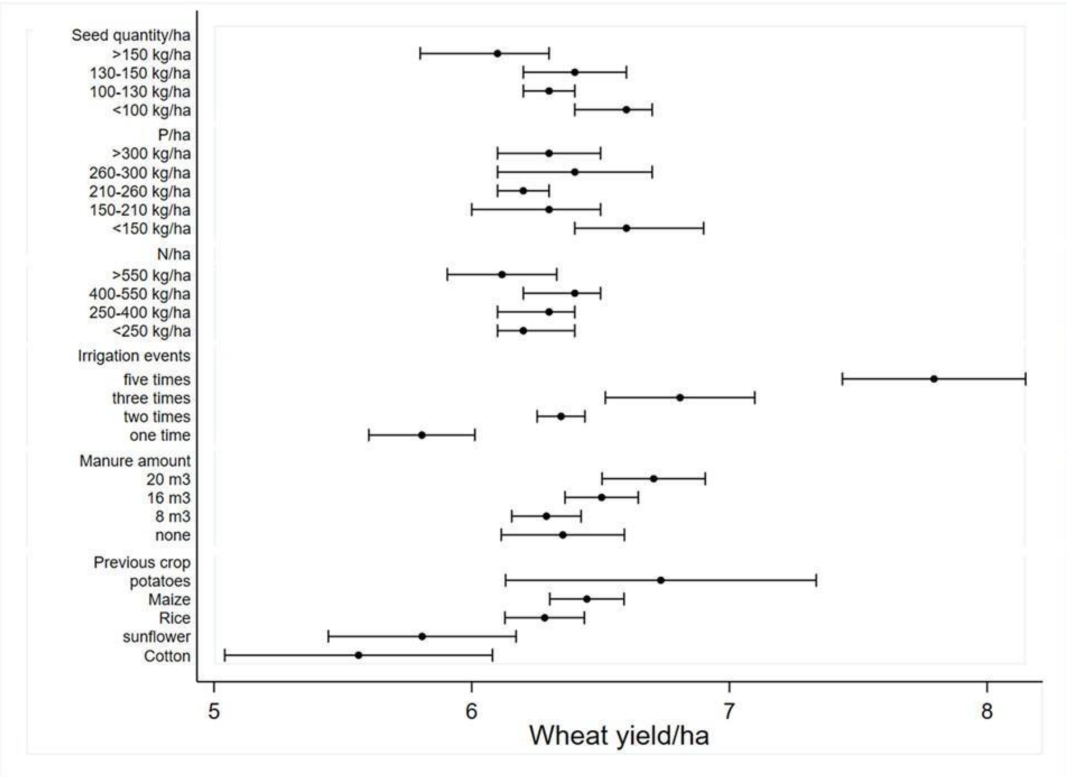


Figure 3. Wheat yield response to the individual agronomic variables in the four study areas in Egypt (survey 2021/22).

4. Discussion

Increasing the domestic wheat production is imperative for Egypt in view of disrupted wheat value chains and soaring wheat prices on international markets in relation to the Russia–Ukraine war. An expansion of the irrigated cropland area is limited by water availability. Two options for moving toward achieving national self-sufficiency in wheat concern (1) increasing the area share under wheat cultivation, mainly by replacing winter clover and by wheat, and (2) increasing wheat yields on existing irrigated cropland.

4.1 Increasing Wheat Production

Only <20% of the irrigated winter cropland area in the study area is currently cultivated with wheat, compared to nearly 30% in China [21], 42% in Europe [22], and up to 60% in South Asia [23]. Replacing Alexandrian clover (berseem) with wheat as the dominant winter crop could potentially increase the cultivated wheat area by up to 0.6 million ha in the Nile Delta [24], thus effectively counteracting current shortfalls in wheat imports. This is, however, no stand-alone strategy, as it would strongly affect feed production and, thus, jeopardize the supply with meatand milk, shifting the bread shortage to a protein shortage problem. In addition, strong fiscal incentives would be needed to substantially increase the economic attractiveness of wheat cultivation. For instance, the net income of cultivating one feddan (0.4 ha) of wheat was estimated at EGP 2991 (equivalent to USD 178) in 2019 [25]. This means that smallholders receive a monthly net income of only USD 29 from cultivating one feddan of wheat. Such low economic attractiveness of wheat production has been highlighted by local purchasing prices being strongly correlated with the cultivated area of wheat in Egypt [6]. Consequently, the wheat area is expected to expand with increasing farm gate prices for wheat. Policies increasing the economic attractiveness of producing wheat are urgently required. Beyond such economic incentives, it appears paramount to also increase the social acceptance and recognition of farming for the younger generation [26]. A mean age of wheat farmers of 56 years, compared to the mean age of 26 years of the whole population in Egypt [27], highlights the lack of interest in farming among the younger generation [28].

This trend, if not reversed, may jeopardize the future of agriculture and food production in Egypt and possibly beyond [29].

On the other hand, with an average yield of about 6 t/ha, wheat farmers in the Nile Delta of Egypt produce far below the yield potential and below the yield level achievable on a research station or by a small number of progressive farmers [30].We hypothesized that poor land, water, and crop management practices are responsible for the currently large yield gaps [31], and we investigated possible reasons and ways forward toward achieving wheat self-sufficiency.

4.2 Unbalanced Nutrient Supply

Nitrogen and P fertilizers are applied far in excess of the nutrient uptake or crop demand [32] of about 23 kg N and 2.2 kg P per ton of wheat grain [33]. With an average of 6.5 t/ha in El Beheira Governorate, this figure implies that 140 kg N and 16 kg P/ha are needed to compensate for current rates of nutrient removal. At mean rates of 300 kg N and 95 kg P/ha, the current application exceeds crop demands by factors of 2.5 (nitrogen) and 6 (phosphorus). Excessive application rates of mineral N and P fertilizers appear to induce an imbalance in the provision of other plant nutrients. Thus, micronutrients are widely deficient in soils of the "old land" (mainly Zn) [34], and in the "new land" (mainly Mn, Fe, B, and Zn) [35]. Suchmicronutrient deficiencies are reportedly affecting yields of wheat [36] and other crops [37]. The current subsidy policies favor unbalanced wheat nutrition and need to be amended by supporting farmers with K fertilizers while encouraging the development of new and balanced micronutrient fertilizer formulations. In addition, excessive and wasteful nutrient applications entail widespread N- and P- related environmental problems [38] and water pollution in Egypt [39]. According to El Kader [40], the use of excessive amounts of N and P fertilizers has entailed serious recent environmental consequences. The associated eutrophication of surface water bodies has resulted in the growth of harmful algae, the depletion of oxy-gen, and the death of fish and other aquatic organisms. In addition, eutrophication affects the quality of drinking water and entails a further exceeding of the planetary boundaries [41].

4.3 Water Deficit

Irrigation water is key to high and stable wheat yields. Our data showed that different irrigation strategies and frequencies are by far the most yield-effective production factor, explaining nearly 40% of the observed yield variability. This is particularly relevant in water-strapped environments in the desert margin (i.e., AbuEl Matamir Division) and in soils with low water-holding capacities (i.e., Kafr El Dawar Division). In those areas, large observed yield variabilities are related to poor or unreliable water supply and increase the riskiness of production or the uncertainty in the outcome of investments in agricultural production. Given prevailing water limitations and growing competition for water resources from industry and urban development, water for agriculture in general and for wheat production specifically must be used more efficiently. This may be achieved by restricting wasteful overhead sprinkler applications (i.e., use of drip irrigation) [42], by encouraging the use of effective agronomic production methods (i.e., mulch culture) [43], and by using water-efficient wheat genotypes [44]. Yet another strategy concerns retaining water in the soil matrix by increasing organic matter contents. Current application rates of organic amendments (i.e., farmyard manure) are rather low but are required for improving soil water-holding capacities [45], particularly on the sandy soils in the “new land” [46]. Finally, applying raised-bed technologies can have a significant impact on wheat production under conditions of water shortages by reducing crop water use by up to 25% while increasing wheat grain yields [47]. Most of these strategies are knowledge- intensive, requiring training of farmers, strengthening extension, and generally improving farmers’ access to modern production technologies.

4.4 Future Needs

Expanding the area cultivated with wheat and increasing grain yields per unit area require effective policy interventions, ensuring incentivizing wheat prices (similar or above the price of imported wheat, which is often of lesser quality). Farmers may be encouraged to cultivate larger shares of their holdings with wheat when fixed price ceilings are declared before the beginning of the cultivation season. Yields can increase and yield variability, and hence, uncertainties may be reduced by new micronutrient-containing fertilizer formulations. The use of such fertilizers may be stimulated by providing them at subsidized prices.. Additionally, the development and extension of wheat genotypes with higher drought tolerance or better water use efficiency should be a high priority for the Ministry of Agriculture and Land Reclamation and relevant research institutions in Egypt.

The highly varied application rates of amendments and farm inputs and the overuse of some mineral fertilizers (in this case, mainly mineral N and P) also reflect a lack of knowledge at the farmer’s level. There is an urgent need to improve agricultural extension services to provide relevant information, training, and technology recommendations to wheat-producing farmers. This also entails improved and location-specific recommendation of fertilizer types and rates; of irrigation frequencies; and of the preparation, storage, and application of organic amendments.

The implementation of policies that provide incentives to farmers to expand their wheat-growing area and adopt sustainable agricultural technologies has the potential to significantly increase domestic wheat production and reduce dependence on costly and inconsistent wheat imports. These policies may include measures such as subsidies or tax breaks for investments in agricultural technology and equipment, support for the research and development of new andimproved wheat varieties, and funding for extension services to provide farmers with the necessary information and resources to optimize their agricultural practices. Moreover, strengthening agriculture extension services is a critical component of any policy designed to increase wheat productivity. Extension services provide farmers with access to knowledge and training on the best practices for crop management, pest control, and soil fertility management. By adopting more advanced technologies and practices, farmers can improve their yields and produce higher- quality crops.

While a substantial amount of research has been conducted on wheat production in Egypt, there are several areas requiring further study to improve wheat productivity and ensure food security:

(1) Climate Change: Climate change is expected to affect wheat production in Egypt, particularly in terms of water availability and quality. Future studies should focus on identifying effective adaptation strategies for wheat production in a changing climate, including the development of drought-tolerant wheat varieties and improving water management practices.

(2) Soil Health: Soil health is critical for sustainable agriculture and wheat productivity. Future studies should investigate the impact of practices such as cover cropping, crop rotation, mulch culture, and reduced tillage to foster soil health, nutrient cycling, and the water-holding capacity of wheat soils.

(3) Market Access: Improving market access and facilitating trade is critical for ensuring that wheat farmers receive fair prices for their crops. Future studies should examine factors influencing market access and trade, including policy and infrastructure barriers.

(4) Technology Adoption: Technology adoption is critical for improving wheat productivity in Egypt. Future studies should investigate factors influencing farmers'adaptive capacity to adopting site-specifically adapted new technologies.

5. Conclusions

In conclusion, the present study identified inappropriate agricultural practices that are related primarily to irrigation and fertilization scheduling and intake as key factors contributing to the low yields that result from a lack of knowledge and extension services. However, through the implementation of sustainable irrigationand fertilization practices, there is a high potential for a substantial increase in yields and, consequently, the total domestic wheat production in Egypt. Increasing domestic wheat production in Egypt is imperative to reduce the increasing economic burden of wheat imports, to support farmers' livelihoods, and to render the country more resilient to disruptions in the international wheat supply chains. Two promising strategies concern (1) an increase in the area share cultivated to wheat via partial substitution of berseem clover with wheat as the dominant wintercrop and (2) implementing effective and sustainable agronomic practices to reduce the yield gap while increasing farmers' income.

Although improving wheat productivity among smallholder farmers in Egypt is critical to achieving food security and reducing poverty in the country, smallholderfarmers face numerous challenges, including limited access to knowledge, technology, markets, and credit facilities, which limit their productivity. To addressthese challenges, it is essential to implement comprehensive approaches that include providing extension services, increasing access to credit, improving access to markets, and promoting the use of appropriate technologies. In addition, efforts should be directed toward developing appropriate policies and strategies that support smallholder farmers, such as pricing policies that provide them with fair returns and infrastructure development that supports agricultural productivity. These interventions need to be accompanied by targeted capacity-building programs that equip farmers with the necessary knowledge and skills to adopt new technologies and practices that enhance productivity. Moreover, given the importance of wheat in the Egyptian diet, there is a need to invest in research and development to develop new wheat varieties that are more resilient to changing climatic conditions, water scarcity, and pests.

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Chapter 6

Wheat Farmers’ Perception of Constraints and Their Adaptive Capacity to Changing Demands in Egypt

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Abstract

Most of the approximately 105 million Egyptians depend on wheat in the form of *baladi* bread for their daily diet. Millions of smallholders along the River Nile have produced wheat for millennia; however, in more recent history, the wheat demand and supply ratio has dramatically changed. The first wheat imports in Egyptian history were in 1966. Today, domestic production meets only half of the wheat consumption, and Egypt has become the largest wheat importer in the world. Before the Russia–Ukraine war, 85% of the wheat imports to Egypt came from Russia and Ukraine. The war and the associated disruption of the wheat supply chains has put Egypt on the top list of so-called "developing countries highly threatened by food crises". Against this backdrop, we analyzed decision-making factors and perceptions of wheat-producing smallholders in the Nile River Delta, the wheat basket of Egypt. The study draws on nine months of empirical fieldwork in the Nile River Delta. We employed a mixed approach to data collection, combining interviews and focus group discussions with smallholders, experts, and agriculture extension agents with transect walks and field observations. In total, 246 randomly selected wheat-growing smallholders were interviewed in four divisions in the Nile River Delta. Our findings show that the production of wheat by smallholders is highly influenced by system-immanent factors, such as subsistence need for home consumption and the presence and intensity of animal husbandry, as well as by external factors, such as the domestic prices for wheat determined by the government in each season and the time of the declaration of these prices. These factors affect smallholders' decisions to increase or decrease their wheat cultivation area. However, the study also showed that the factors influencing farmers' decisions to grow wheat or implement innovative practices vary across different areas within the same region. Smallholders struggle with poor access to fundamental production factors and are discontented with the low provision of extension and support services as well as poor market structures. These constraints act as disincentives for smallholders to produce (more) wheat. They need to be addressed and eliminated to increase domestic production and to reduce Egypt's dependency on expensive and unreliable wheat imports.

Keywords: food security; wheat self-sufficiency; Egypt; smallholders; agricultural policies

1. Introduction

1.1 Background

In many parts of the world, smallholder farmers are the backbone of agriculture and for food security. Smallholder farmers produce 50 to 80% of the world's food and up to 90% in the Global South [1,2]. Smallholders are defined as farmers producing on relatively small land holdings, mainly with family labor, and using parts of the production for their own household consumption [3]. Agricultural productivity, sustainability, and agricultural transformation largely depend on the decisions of smallholders to grow certain crops at a given time and quantity. However, the process of decision making at the smallholder level is complex and influenced by many factors. Tanvi [4] grouped those in physical factors, economicfactors, farmer preferences, crop profiles, and the availability of resources. Talawar [5] conducted a study on smallholders' decision making based on physical factors such as soil quality and the availability of water. Other studies show crop attributes such as a resistance to pests and diseases, growth cycles, and fertilizer requirements as important factors influencing smallholders' decision making, while other authors stress the role of the availability of extension servicesand inputs such as farm machinery, fertilizers, and pesticides [5]. Morgen [6] considered economic factors as fundamental for smallholders' decision making, stating: "Essentially, farms are businesses with economic objectives". On the other hand, Briggs [7,8] showed that economic factors, such as projected market prices and crop production costs, play smaller roles in the decision-making processes of smallholders. Greig [9] attributed a "limited commercial nature of smallholder agriculture" and found that smallholders' decisions to produce a certain crop at a given time and quantity are influenced by factors such as workload, experiences and traditions rather than by purely economic considerations.

1.2 Smallholders in Egypt

In Egypt, 90% of all farmers are smallholders with less than 2 ha of cropland; 50%of all farmers in Egypt have even less than 0.4 ha [1,10]. These farms employ a mix of traditional and modern agricultural practices, adopting technologies such as improved seeds and mechanization to enhance wheat cultivation. Average wheat yields on these farms range from 3 to 6 tons per hectare, but with better access to agronomic practices, higher yields of up to 8.5 tons per hectare are achievable. Inputs like wheat seeds, fertilizers, and pesticides are procured from local supply stores in the private market or cooperatives, with govern- ment subsidies. However, challenges exist in ensuring timely and sufficient supply [11].Smallholder farming is the backbone of agriculture and for food security in Egypt. It contributes significantly to livelihoods and employment in rural areas, to land and water use, and to social belonging and cultural heritage of large parts of the population. However, policies of different Egyptian governments over the past decades led to a reduction in agricultural subsidies and extension support for smallholders, incentivizing large-scale industrial production of export crops, ratherthan staple food production, and generally to a disaggregation and reconstitution of the smallholder’s class in Egypt.

1.3 Wheat Importance in Egypt

The population of Egypt is growing at 2.2% per year [11]. It is expected to reach 157 million people by the year 2050 [11]. Projections indicate that the demand for wheat will double by 2050 [12]. Demographic growth combined with dwindling support for smallholders will further increase the reliance on imported wheat [13]. On the other hand, policies have supported the expansion of agriculture to land inthe desert (the “new lands”), but with a focus on export-oriented commodities suchas citrus. Over the years, Egypt not only became an important exporter for certainagricultural products; it also became the largest wheat-importing nation in the world [14]. Wheat is a strategic commodity and historically the most important cropin Egypt. Egyptians derive one-third of their daily caloric intake and 45% of their protein intake from wheat-based food [15], mainly in the form of bread called aish *baladi* (aish means “life” in Arabic).

The political stability in Egypt is closely linked to the price and availability of *baladi* bread. For example, the rise of the prices for *baladi* bread was the main reason for sparking the Egyptian “bread riots” in 1977. Thirty-four years later, the prices of *baladi* bread also played a critical role in the Egyptian revolution in 2011, where the call of the revolution was “bread, freedom, and social justice”. After decades of political negligence of wheat-producing smallholders on the one hand, and population increase of about 2 million per year on the other hand (Abdalla, et.al., 2022), only less than half of the national wheat consumption can be met by domestic pro- duction; the rest has to be covered by wheat imports [16]. In 2018, from the national wheat consumption of 18.5 million metric tons, about 12 million tons had to be imported [17]. In 2020, Egypt had a total wheat consumption of 20 million metric tons of which 13.5 million were imported [18,19]. In recent years, Russia and Ukraine were by far the most important wheat suppliers to Egypt. About 60 to 66% of the wheat imports to Egypt (depending on the years) came from the Russian Federation and another 20 to 25% were imported from Ukraine. This was followed by smaller amounts from Romania, France, and the United States [19]. In 2021, briefly before the war, Russia and Ukraine together contributed 85% of the total wheat imports to Egypt [18,19].

About 61% of the Egyptian population (63.5 million people) from the total population of about 105 million, especially the poorer ones rely on *baladi* bread for their day-to-day diet. *Baladi* is sold under a state-subsidized food card system [19]. The government fixed the price of *baladi* at EGP 0.05 per loaf (equivalent to USD 0.01) in January 2022, which is less than one-tenth of the actual production costs [17]. This bread subsidy program has become a massive economic burden on the Egyptian state budget. For instance, in the fiscal year 2019/20 alone, the government allocated more than EGP 89 billion (USD 5.69 billion) for bread subsidies. In the fiscal year 2020/21, bread subsidies amounted to EGP 84.5 billion (USD 5.4 billion) [20]. Most of these subsidies targeted the wheat supply chain, from buying wheat from producers to flour milling, via bread production in bakeries, to selling it to the end consumers [21]. They, however, largely neglectedsupport for wheat-producing smallholders.

1.4 The Impact of the Russia–Ukraine War on Egypt

In 2022, the value of the Egyptian currency dropped by about 60% against the USD (EGP 15.7 to USD 1 in January 2022 compared to EGP 24.7 to USD 1 in December 2022) [22]. The currency devaluation was partly a result of the massive trade deficit of the Egyptian economy. This faced markets in Egypt with a disruption in the supply chains of several essential commodities, in addition to a significant price hike for food coupled with a lack of foreign currencies [23].

The recent UNCTAD report [18] highlighted that many countries in the Global South that rely on food imports, and Egypt specifically, are facing a double burden of massively increasing prices for food imports and a depreciation of their currencies against the USD. This increases the risk of hunger for millions of people, particularly the poor, in these countries. In October 2022, the wheat prices in the international market increased by 89% [18]. Additionally, the average exchange rate between the USD and respective national currencies in food import-depended countries of the Global South increased by 10–46%. Combined the real food import prices increased between 106 and 176% [18].

The UN-CTAD report showed that exchange rate effects are significant drivers of rising food import bills, contributing to inflation, loss of purchasing power and foodinsecurity in the impacted nations. After Mauritius, Pakistan, and Ethiopia, Egypt is the fourth-most affected country in the world by these exchange rate effects. For instance, the wheat import bill in Egypt increased by 112% between 2020 and2022 due to the combined effects of increased wheat prices on international markets and currency devaluation. As a result, to import the same amount of wheat as in 2020 (13.5 million metric tons), the additional costs are estimated at USD 3 billion in 2022, which is equivalent to 20% of the total expenditures for food import in Egypt [18]. This problematic wheat import situation jeopardizes national food security, particularly for the poorer parts of the population. Despite a World Bank loan of USD 500 million in June 2022 [19] to improve the access to bread for poorer households through the Emergency Food Security and Resilience Support Project, food insecurity is dramatically increasing and threatening the social-political stability in Egypt.

Already in 2014, the Government of Egypt issued the vision of substituting costly and increasingly insecure wheat imports by increasing domestic wheat productionin its "Egypt Sustainable Development Strategy Towards 2030". The strategy wasaimed at increasing domestic wheat production and attaining a wheat self- sufficiency level of 74% by 2017. However, in reality, wheat self-sufficiency in 2017 was only 43% [14].

1.5 Study Objectives

Against this background, this study aims to determine the main challenges facing domestic wheat production in Egypt by:

1. Determining the key factors influencing smallholders' decisions to grow wheatand adopt efficient cultivation practices;

2. Showing the perspectives of wheat-growing smallholders on their (dis-)incentives to increase or decrease their wheat production; and

3. Evaluating changes in key determinants, influencing smallholders' decisions over two decades (2000–2020).

4. Testing our hypothesis that the factors impacting their decision-making process differ across the four study regions due to varying levels of access to water, labor, market opportunities, and soil types.

The research focused on four municipal divisions in the Nile River Delta of Lower Egypt, which is traditionally the main wheat-growing area and the "breadbasket" of the country.

2. Methods

2.1 Description of the Study Area

About 57% of the wheat-producing land in Egypt is located in the Nile Delta [24]. Beheira Governorate covers 9826 km2 west of the Rosetta branch of the River Nile. The area is densely populated by about 7 million people, of which more than 70% are working in agriculture. The area is well connected by four highways to the central markets of Cairo and Alexandria. It consists of 13 centers, 14 cities, 84 rural municipalities, and 407 villages [25]. While representing only 15% of the total agricultural land in Egypt [26], Beheira Governorate produces 60–65% of the total wheat of the country. Spring wheat is grown in rotation with irrigated summercrops and vegetables on relatively small land holdings in the peri-urban fringes of the “old lands”, and with partial pivot and spray irrigation in fallow rotation systems on large land holdings in rural areas of the “new lands” [27]. Four municipal divisions were selected as study areas, based on their diversity in water availability, market access and soil type. The research transect extends between

(1) Al Mahmoudiya Division, consisting of 14 villages located on the Rosetta branch of the Nile (rural–moist scenario), (2) Kafr El Dawar Division, consisting of 31 villages located along major highways with very good market access (urban– moist scenario), (3) Abu El Matamir Division, consisting of 24 villages located on the desert margin (rural–dry scenario), and (4) El Nubariyah Division, representing the cultivated desert (urban–dry scenario) (Figure 1).

Within each of the study divisions, different wheat production and marketing methods have evolved over time in response to different external pressures (policies, water availabil- ity and pricing, input, and product process) and system- immanent drivers (the availability of production factors and farmers’ perceptions) that were systematically characterized and categorized [14].

2.2 Data Collection

Using a mixed-method approach, we collected both qualitative and quantitative data from four municipal divisions in Beheira Governorate of Lower Egypt. Qualitative data were collected through 28 open interviews with wheat-growing smallholders, 12 with agricultural extension agents, and 8 with agricultural cooperative representatives. In addition, we combined 12 focus group discussions (FGDs) with participatory observations and transect walks. To collect quantitative data, we selected 246 wheat-growing smallholders in four municipal divisions of Beheira Governorate, namely Al Mahmoudiyah, Kafr El Dawar, Abu El Matamir, and El Nubariyah, using random sampling methods. Interviews were conducted during the 2020/2021 agricultural season using a pre-tested questionnaire. The distribution of the sample (number of smallholders) was proportional to the respective number of farms in each division (corresponding to 0.6% of its total number). The sample size was sufficient to achieve the desired level of statistical precision (95% confidence interval with a margin of error of 5%). Moreover, the sample size allowed for subgroup analyses and comparisons across different variables of interest, such as farm size and farming experience, providing a robust basis for drawing meaningful conclusions. The perceptions of wheat-growing smallholders were assessed using a five-point Likert scale. The Likert scale allowed the interviewees to indicate (1) the extent to which they agreed or disagreed to certain statements related to wheat production, (2) how they assess certain external pressures and system-immanent drivers (very poor = 1, poor = 2, acceptable = 3, good = 4, excellent = 5), and (3) how they perceive changes of the same between 2000 and 2020 (much worse = 1, worse = 2, same = 3, better = 4, much better = 5). This provided a structured and standardized approach to data collection, allowing comparisons across different groups of respondents.

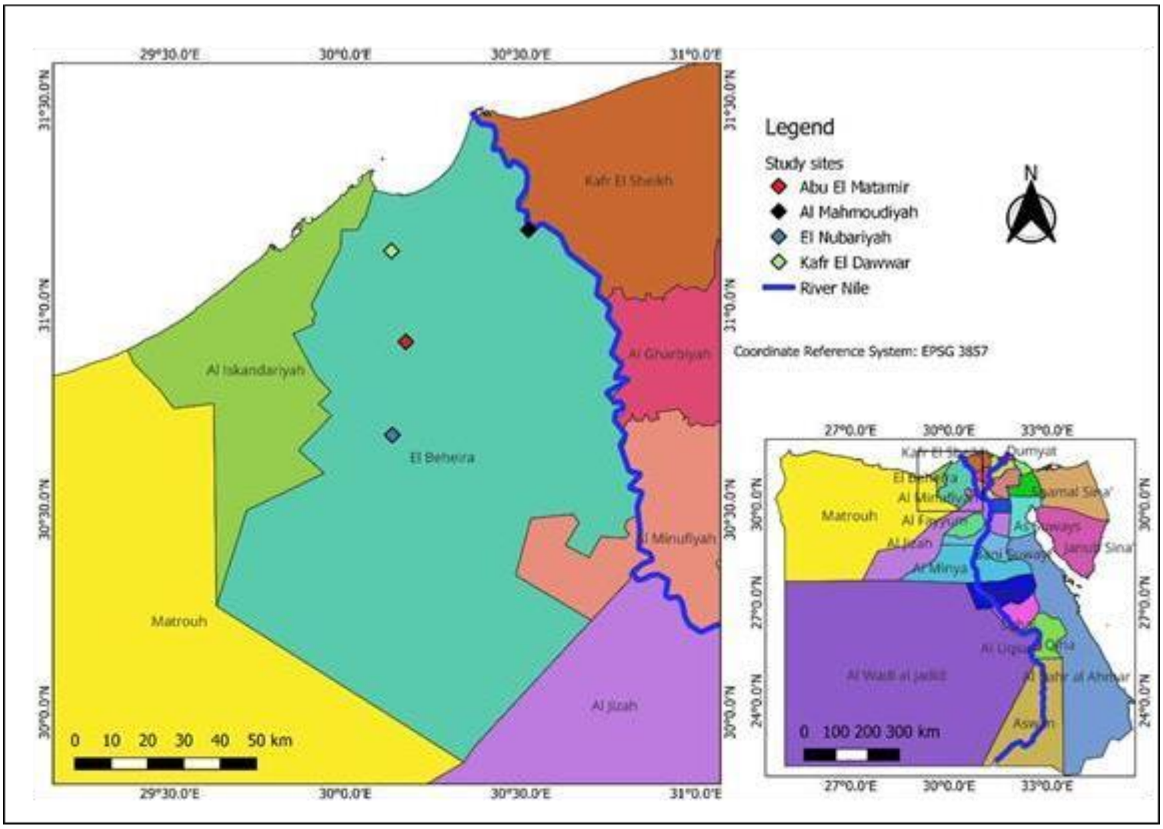

Figure 1. Study locations (municipal divisions) within El Beheira Governate in northern Egypt. Al Mahmoudiya, Kafr El Dawar, and Abu El Matamir Divisions represent the "old lands", while El Nubariyah Division represents the "new lands".

2.3 Data Analysis

2.3.1 Qualitative Data Analysis

The qualitative information empirically collected from various sources, including 28 open interviews with wheat-growing smallholders, 12 interviews with agricultural extension agents, 8 interviews with agricultural cooperative representatives, and 12 focus group discussions (FGDs) were triangulated and combined with participatory observations and transect walks to capture a comprehensive understanding of the research topic.

The process of data analysis followed a systematic and iterative approach. Initially, the interviews were transcribed verbatim, and detailed field notes were documented from the participatory observations and transect walks. This ensureda comprehensive record of the collected data. The data were then coded, and we carefully examined the transcripts, field notes, and other data sources to identify meaningful units of analysis, such as phrases, sentences, or paragraphs, and assigned descriptive codes to capture emerging themes and patterns. The coded data were subjected to a rigorous analysis to identify and develop themes that encapsulated the underlying patterns and trends present in the dataset.

Triangulation was employed to enhance the deepness and trustworthiness of the findings. We examined the convergence and divergence of findings across different data sources, such as interviews, FGDs, and observations. This comprehensive approach allowed for a more nuanced understanding of the research topic and provided opportunities to explore complex variations in perspectives and experiences.

Throughout the analysis, relevant quotations and excerpts from the data were meticulously selected to add background information and/or to provide supportingevidence. These excerpts were chosen to enrich the analysis with concrete examples and participant voices. By including these quotations, the study ensures more transparency and credibility of the findings.

The final stage of the qualitative data analysis involved synthesizing and reporting the key findings. The identified themes, subthemes, and supporting evidence weresynthesized into a coherent narrative, highlighting the most salient insights derived from the qualitative data. The findings were directly related to the researchobjectives to deepen the understanding of the research subject.

2.3.2 Quantitative Data Analysis

The analysis of the quantitative data involved employing descriptive statistics, such as frequency counts, percentages, and means, using STATA software. These statistics were utilized to describe wheat production characteristics and to assess the perceptions of wheat-growing smallholders.

To gain a deeper understanding of the dataset's structure and to identify important factors, a Principal Component Analysis (PCA) was performed. The PCA allowed for the transformation of a high-dimensional dataset into a lower-dimensional representation while preserving essential information. This phase aimed to identify the key factors that influence wheat-growing smallholders decision making by applying PCA to Likert scale data. The dataset consisted of 246 samples with 10 variables, which captured various attributes of smallholders and their farms.

In addition to the PCA, a linear regression analysis was conducted to explore whether significant differences existed between the PCA factors and the four study areas. This analysis aimed to assess the relationship between the identified PCA factors and the geographic study areas.

3. Results

3.1 Key Production Characteristics of Wheat-Growing Smallholder Farms

The irrigation in the "old lands" in El Mahmoudiya, Kafr El Dawar, and Abo El Matamir divisions mainly works through pump surface irrigation from canals. In contrast, the wheat irrigation in the "new lands" in El Nubariyah division is mainly a spray irrigation system. The summer-winter rotations on the clay soils in El Mahmoudiyah and Kafr El Dawar divisions are mainly maize–wheat and rice– wheat. However, in Abo El Matamir division with clay loamy soils, potatoes-wheat, maize-wheat, sunflower-wheat rotations are more common. The summer–winter rotations in the sandy soil of Nubaria division are peanuts–wheat, maize–wheat, potatoes–wheat, and sesame–wheat.

The survey conducted with 246 wheat- growing smallholders showed the following socio-economic characteristics as shown in Table 1. The results reveal that wheat-growing smallholders have a mean age of 56 years, with a minimum of 32 years and a maximum of 79 years, and a mean experience in wheat cultivation of 30 years. The smallholders hold land with a mean of 1.1 ha, with a minimum of 0.2 ha and a maximum of 2.3 ha. The mean of the wheat yield is 6.4 t/ha, with a minimum of 4.2 t/ha and a maximum of 8.5 t/ha.

Table 1. Key characteristics of wheat-growing smallholder farms (source: field survey 2020/21 growing season).

	Age of Farmer (Years)	Farming Experience (Years)	Farm Size (ha)	Wheat Yield (t/ha)
Mean	56	30	1.05	6.4
Range	47	40	2.1	4.2
Minimum	32	10	0.2	4.2
Maximum	79	50	2.3	8.5
Count (n)	246	246	246	246

3.2 Factors Influencing the Decision of Smallholders to Grow Wheat

Both results from the open interviews and questionnaire-based interviews determined ten key factors influencing the decision of smallholders to grow wheat. The influence of these factors was evaluated and ranked based on smallholders' perspectives, as shown in Figure 2.

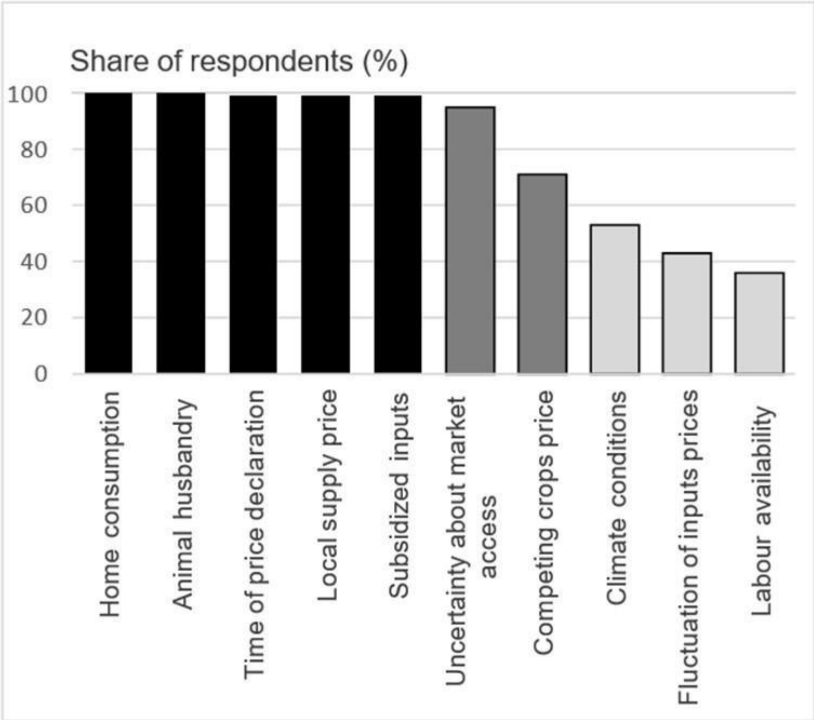

Figure 2. Key factors influencing the decision of smallholders to grow wheat (source: field survey 2020/21 growing season).

In all cases, the household consumption of wheat (subsistence needs) and animal husbandry (crop residue uses and forage production) determined smallholders' decisions to grow wheat as system-immanent drivers. In 99% of all cases, farm- external determinants, namely the time of the price declaration by the Ministry of Supply and Internal Trade, the local supply price and the availability of subsidizedinputs, influenced the decisions of smallholders. In 95% of the cases, uncertainty about market access influenced the decisions. Other external factors included theprices of competing crops (71%), climatic conditions (53%), fluctuation of input prices (43%), and labor availability (36%).

Household consumption refers to the share of the agricultural production used for own consumption to secure households' needs. Smallholders with large subsistence needs tend to produce wheat for their own consumption. However, profitability can significantly influence decisions of increasing or decreasing the share of land on which they grow wheat, as highlighted in the below statement of a smallholder:

"*Wheat is an essential crop for us as most of our food is wheat-based. I own 1.5 hectares, and 80% of my land share is for clover production and 20% for wheat, but if the wheat production provides higher revenue, I would increase the share ofwheat in substitution for the clover share area."* Smallholder, FGD No. 1

Animal husbandry refers to the livestock smallholders' own. This influences the need for wheat straw as animal feed or as bedding material. Thus, smallholders owing livestock perceive wheat straw as an important by-product of wheat production that can be stored for long periods and that can be sold if needed. A statement of a smallholder underlines this:

"*We use the wheat straw to feed our animals and in the case of need, we can easily sell it to our neighbors*." Smallholder, FGD No. 1

Price declaration refers to the time when the Ministry of Supply and Internal Trade declares the local wheat supply price, meaning the price that smallholders obtain for their wheat when selling it to the national public storage silos. In this study, many smallholders mentioned frequent delays by the Ministry declaring these prices. This is a crucial disincentive for them to invest in growing more wheat, or to expand the share of their wheat-growing area. The ministry fixes the local wheat supply prices annually, mostly by the end of the growing season, differentiated in three price levels according to wheat quality and purity. However, most smallholders prefer to sell their wheat to private intermediate traders rather than to public storage silos. They justified this by avoiding transportation costs, waiting lines at the silo gates, and conflicts during the inspections at the silo gates. This is also illustrated in the following statements by two smallholders:

"Despite the lower price the traders pay to us, I prefer to sell to traders rather than to the public silos. We spend almost one day to sell our wheat to the public silos and in the waiting lines. In addition to the transportation fees." Smallholder, Interview No. 1

"Most often the amount of wheat surplus we intended to sell after saving our home consumption does not deserve the effort of transportation and the time wasted inlines." Smallholder, Interview No. 4

Other smallholders criticized the wheat purchasing process at the public silos:

"The purchasing and inspection process at the public silos is not fair, and in mostcases, you need to bribe the inspector to avoid the devaluation of the wheat quality." Smallholder, FGD No. 2

"The inspectors sometimes devalue the wheat to grade three which isapproximately EGP 100 lower than grade one for each ardab." Smallholder, FGD No. 6

"Traders always deliver large amounts of wheat, and they have their connectionsto avoid all challenges at the public silos." Smallholder, FGD No. 9

Local wheat supply price refers to the yearly price set by the ministry of supply for purchasing wheat from the domestic market.

Subsidized inputs refer to the fertilizers sold to smallholders by agricultural cooperatives at lower prices than in the private market. Such subsidies are largely limited to mineral nitrogen fertilizers.

Uncertainty about market access denotes to what extent smallholders can be certain about selling their wheat at a given time and price. In the 2016 growing season, the Ministry of Supply and Internal Trade ended the purchase of wheat atthe public silos earlier than initially declared, saying that the targeted amount of wheat was achieved [28]. This causes serious problems for many smallholders asshown in the following statements:

"In the 2016 season I lost all my income from wheat because the government stopped the local wheat supply suddenly ahead of the officially scheduled de- clared date." Smallholder, Interview No. 2

"In the 2016 season I increased the size of wheat after the Ministry declared in November 2016 the price of local wheat supply is 1300 EGP per ardab, and suddenly by the end of the season the Ministry declared a different purchasing price of EGP 420 per ardab which was a shock to me and all wheat growers."
Smallholder, Interview No. 9

"The government prefers to rely on importing wheat from global markets rather than the local market, and always supports wheat importers. I do not believe thatthe government wants to attain wheat self-sufficiency. The government fighting against smallholders and siding with importers." Smallholder, Interview No. 12

Competing crop prices refer to the prices of other winter crops competing with wheat cultivation on the same farm area. The most common winter crops competing with wheat in the study areas are broad beans and Alexandrian clover (bersim).

Climate conditions refer to the weather events affecting wheat quantity and quality, such as floods and high temperature fluctuations during the growing season. Smallholders highlighted the significant negative impact on wheat yield and quality associated with wheat lodging due to excessive rain combined with intense winds. In addition, sudden heat waves during the growing season enhance infections with wheat rust and can lead to massive yield losses. This is exemplified in the following statements:

"In the last season I lost almost third of my grain yield due to the intensive rain in combination with strong wind." Smallholder, Interview No. 12

"The machinery harvest process became impossible after wheat lodging and we must harvest it manually which requires longer time, manpower, and higher cost." Smallholder, Interview No. 8

Fluctuation of input prices refers to the variability in prices for agricultural inputs on private markets such as fertilizers, seeds, machines, and fuel. Despite high price fluctuations in recent years, these hardly affected the share of the land devoted to wheat cultivation, but farmers rather reduced the use of such inputs.

Labor availability refers to the provision and costs of agricultural labor for the small-holder farm. We found, however, that labor availability is not one of the main influential factors in smallholders' decision to grow wheat. Most smallholders in the study area rely on family labor during the season and reciprocal help from neighbors for more labor-intensive farm operations.

Our results show that the wheat production of smallholders in Egypt depends on a variety of underlying system-immanent and external factors. While smallholdersare the backbone of wheat production in the country, many factors limit their ability and willingness to produce (more) wheat. It is essential to understand smallholders' perspectives and to tackle these factors in a "bottom-up approach" to increase food security, to reduce the country's dependency on wheat imports and unreliable supply chains, and to contribute effectively to the "Egypt Sustainable Development Strategy Towards 2030".

Among the system-immanent factors that determine the share of the land area devoted to wheat production are subsistence food needs and requirements for livestock feeding. This all shows that smallholder wheat farming is not an entirely market-based business activity driven by sheer profit maximization but rather an integrated agricultural practice and conduct of life, deeply rooted in food habits and cultural heritage. This is also highlighted in a statement of a smallholder.

"Wheat cultivation is traditional. We have been growing wheat for ages and we will not stop growing even though its limited profitability as it is essential to our diets and animal feed." Smallholder, FDG No. 5

However, the life and culture in rural Egypt are changing. There are changes in traditions that act as disincentives and may ultimately lead to abandoning wheat production altogether, as expressed in the following statement by an agricultural extension agent.

"About 10 years ago, we were all backing our bread at home, but since the government started to build bakeries for subsidized bread this culture started to change gradually, and women started to not bake as much as before and become more dependent on the subsidized bread. Therefore, the wheat-cultivated areas started decreasing, as the farmers here did not have another reason to produce wheat. Unless they have animals. Alternatively, farmers started to grow more clover." Agricultural extension agent, Interview No. 2

Furthermore, among the 10 variables identified above, PCA analysis found that three principal components explained 81% of the total variance in the data. This implies that a significant amount of information can be captured by considering only three variables instead of the original 10. Two variables, namely animal husbandry and home consumption were excluded from the model as they had a constant value of zero and were deemed as the main drivers for wheat cultivation.

Further exploration of the principal components allowed for their interpretation. The first principal component (PC1) showed strong positive associations with variables related to time of price declaration, local wheat supply price, subsidized inputs, and uncertainty about market access, suggesting that it represents a measure of policy status. The second principal component (PC2) exhibited high associations with variables linked to production elements such as fluctuating inputprices, labor access, and climate conditions, indicating a production elements component. Lastly, the third principal component (PC3) displayed significant associations with variables related to the prices of competing crops, representing a market component (Component Matrix). Based on these findings, it can be concluded that policy, production elements, and market factors are the primary contributors to the variability in the dataset. This understanding will guide our further analyses and help interpreting results obtained from the regression model.

Component Matrix: Extraction method; Principal component analysis (Source: field survey 2020/21 growing season).

Location	**PC1**	**PC2**	**PC3**
Time of price declaration	0.967		
Local wheat supply price	0.967		
Subsidized inputs	0.967		
Uncertainty about market access	0.700		
Fluctuation of input prices		0.818	
Labors availability		0.798	
Climate condition		0.663	
Competing crop price			0.704

We conducted a linear regression analysis to investigate whether there were significant differences between the three PCA components and the four study divisions.

The results indicated significant differences between the three PCA factors and the four study divisions. The first PCA factor (PC1), "policy", showed significant differences between El Nubariyah Division (urban–dry "D") and the other three divisions (Table 2). However, no significant differences were found among the other three divisions (Figure 3). In El Nubariyah ("D"), the policy factor is considered the most significant factor impacting smallholders' decisions to grow wheat. However, in Abo El Matamir (rural–dry "C"), the policy factor is considered the least significant factor influencing their decisions (Figure 3).

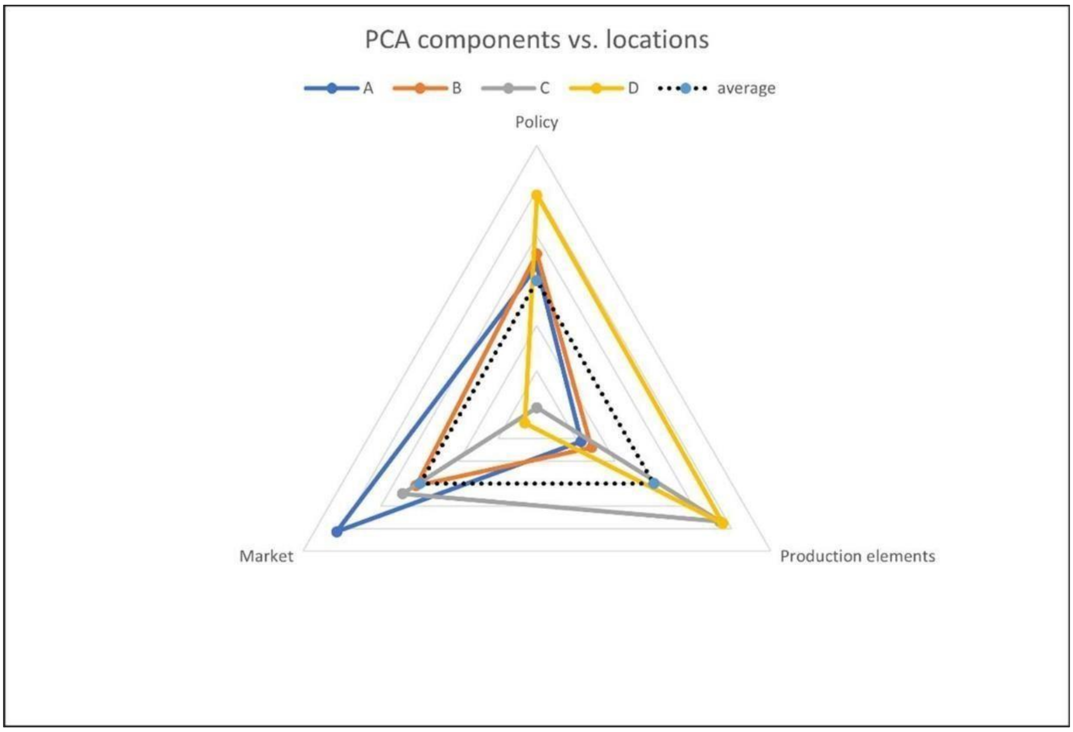

Figure 3. PCA factors' variations in the four study divisions (radar chart) (source: field survey 2020/21 growing season).

Table 2. Pairwise comparisons of PC1 policy factor vs. study divisions (source: field survey 2020/21 growing season).

Location	Contrast	Standard Error	t	$p > t$	[95% Conf. Interval]	
B vs. A	0.0409409	0.0346749	1.18	0.239	− 0.02736	0.109244
C vs. A	—0.4734639	3443276	− 1.38	0.170	− 1.1517	0.204797
D vs. A	0.2378087	0.039233	6.06	<0.001	0.160526	0.315090
C vs. B	—0.5144048	0.3447407	− 1.49	0.137	− 1.1934	0.164670
D vs. B	0.1968678	0.042707	4.61	<0.001	0.112743	0.280992
D vs. C	0.7112726	0.3452289	2.06	0.040	0.031235	1.39131

The second component (PC2), "production elements", showed significant differences among the four divisions. However, there were no significant differences between Abo El Matamir ("C"), and El Nubariyah ("D"). Additionally, there were no significant differences between El Mahmoudiya (rural–moist "A") and Kafr El Dawar (urban–moist "B") (Table 3). In the Abo El Matamir division ("C"), the production elements factor (PC2) was considered the most significant driver. However, in El Mahmoudiya, PC2 was found to be the least significant driver (Figure 3).

Table 3. Pairwise comparison of PC3 production element factor vs. study divisions(Source: field survey 2020/21 growing season).

Location	Contrast	Standard Error	t	*p* > t	[95% Conf. Interval]	
B vs. A	0.0839265	0.1312358	0.64	0.523	−0.17458	0.342436
C vs. A	1.120849	0.1596034	7.02	<0.001	0.80645	1.43523
D vs. A	1.146599	0.3110838	3.69	<0.001	0.53382	1.75937
C vs. B	1.036922	0.1685767	6.15	<0.001	0.70485	1.36898
D vs. B	1.062672	0.3157815	3.37	<0.001	0.44064	1.68470
D vs. C	0.0257498	0.328585	0.08	0.938	−0.62150	0.673002

Lastly, the market factor (PC3) showed significant differences among all four divisions except between Abo El Matamir ("C") and Kafr El Dawar ("B") (Table 4). In El Mahmoudiya ("A"), the market factor was found to be the most significant factor, while it was the least significant factor in El Nubariyah ("D") (Figure 3).

Table 4. Pairwise comparisons of PC3 market factor vs. study divisions (source: field survey 2020/21 growing season).

Location	Contrast	Standard Error	t	*p* > t	[95% Conf. Interval]	
B vs. A	−0.577176	0.1539015	−3.75	<0.001	−0.8803335	−0.2740186
C vs. A	−0.4782684	0.1451015	−3.30	<0.001	−0.7640915	−0.1924454
D vs. A	−1.36689	0.2222701	−6.15	< 0.001	−1.804721	−0.9290591
C vs. B	−0.0989076	0.1830877	0.54	0.590	−0.2617412	0.4595564
D vs. B	−0.7897142	0.2487382	−3.17	<0.001	−1.279682	−0.299746
D vs. C	−0.8886218	0.2433915	−3.65	<0.001	−1.368058	−0.4091855

In conclusion, the factors that determine smallholders' decision making varied across the four different study divisions, depending on their specific characteristics. For instance, in El Nubariyah, which represents the reclaimed desert "new lands", the policy factor had the most significant decision-making influence (Figure 4). This factor included the timing of the deceleration of the annual wheat price, local wheat supply prices, access to subsidized inputs, and uncertainties regarding market access. This was followed by the production elements factor which played a crucial role in El Nubariyah and can be attributed to its specific characteristics. Notably, the predominantly sandy soil requires additional inputs. Moreover, limited access to water, labor availability, and the absence of substantial animal husbandry practices (a key driver for wheat cultivation) contribute to the shift of many stallholder farmers from cultivating traditional crops like wheat to more profitable alternatives such as vegetables and fruits.

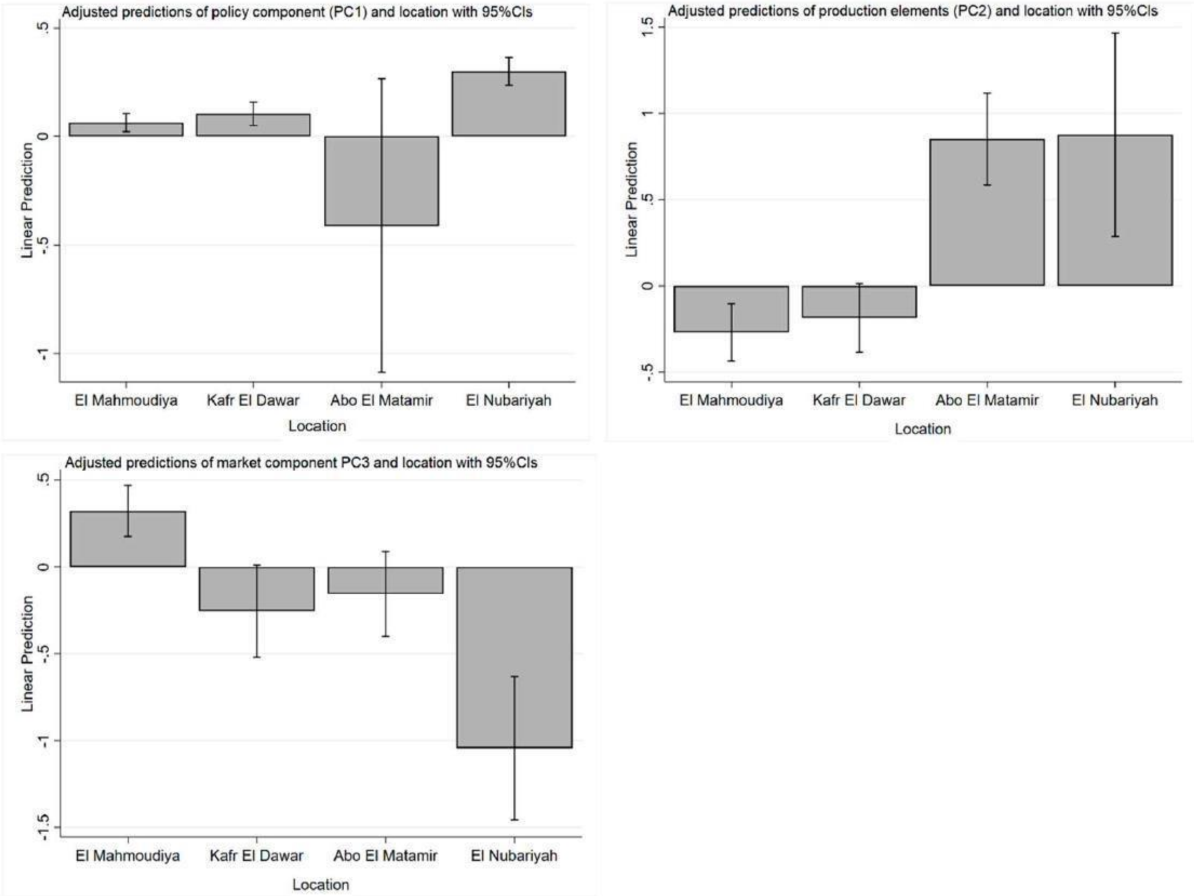

Figure 4. PCA factors' variations in the four study divisions (source: field survey 2020/21 growing season).

Conversely, in Al Mahmoudiya, an "old lands" study division characterized as rural– moist, market factors representing prices for competing crops had the most significant influence on smallholders' decision making to grow wheat. This was followed by policy factors in the area. This can be attributed to favorable conditions for crop growth, including the availability of water and nutrient-rich soil (old land), as well as convenient labor accessibility. As a result, wheat cultivation represents only a small proportion (20%) of the land share, with the remaining 80% of the land dedicated to other competitive crops.

Smallholders' Perception of Factors Affecting Wheat Production

The second part of the primary quantitative data collection was aimed at understanding smallholders' perceptions of factors affecting wheat production. Twelve variables were identified from the open interviews and the FDGs, namely: access to subsidized inputs, access to credit, access to agriculture extension services, access to the market, the availability of farm equipment, the availability of agrochemicals, the availability of labor, the availability of water, environmental conditions, input prices, wheat supply prices, and general profitability. Smallholders were asked to rate these variables on a five-point Likert scale from very poor = 1, poor = 2, acceptable = 3, good = 4, to excellent = 5.

As shown in Figure 5, a majority of the smallholders perceived access to the main production factors as inadequate. Nearly three quarters of all smallholders indicated that input prices are very high (74%), while 58% indicated good access to fertilizers on the private market. Furthermore, 53% indicated that the selling price of wheat to be very low, and 40% indicated low. In addition, 52% of the interviewed smallholders indicated that the subsidized input access was very poor, and 43% indicated poor. Overall, the profitability of wheat production was perceived to be very poor or poor (63% and 37% of the interviewed smallholders, respectively).

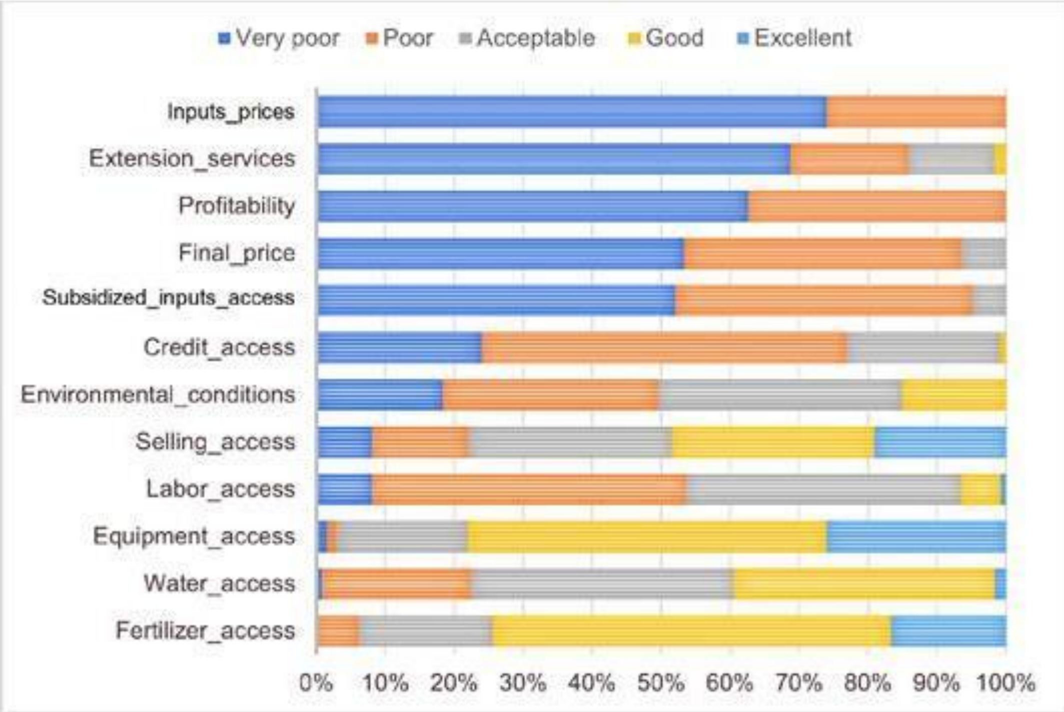

Figure 5. Smallholders' perception of factors affecting their wheat production (source: field survey 2020/21 growing season).

Smallholders highlighted that the cost of wheat production inputs significantly increased in the last five years, specifically after the economic reform program in 2016/2017. In particular, the prices of fertilizers increased considerably, and mostsmallholders cannot afford to buy certain fertilizers any longer. For example, 100%of the respondents said that they eliminated potassium fertilizers from their fertilization program. Moreover, the system of distributing subsidized fertilizers to smallholders by the agricultural cooperatives seems sometimes problematic, as asmallholder stated.

"The Ministry of Agriculture often delays distributing the subsidized fertilizer. Sometimes I receive my quota three or four weeks later than the recommended growing period". Smallholder, Interview No. 13

The interviewed smallholders said that the increase in the wheat production costs massively deteriorated their profitability and that there is little incentive for them to sell their wheat "to the government". This was expressed in a statement by another smallholder:

"Wheat production cost is high, and the government price for wheat is relatively low and not fair to us. We cultivate wheat mainly for our home consumption, andwe use wheat straw for animal feed. We prefer to feed our poultry on the rest of our wheat rather than supply it to the government". Smallholder, Interview No. 7

Many of the smallholders expressed that they feel unsupported and forsaken by the governmental authorities. In the transect walks, we observed a significant lack of agriculture extension services, and in some villages, extension service units did not exist. Based on the Central Administration for Agricultural Extension in Egypt [22], the total number of agricultural extension staff in Egypt decreased between by 2007 and 2018 from 9658 to 2503. This corresponds to a reduction in the extension workforce by 74% within only 10 years. A drastic reduction in governmental support in the form of capacity building and access to production inputs echoes this. Instead, smallholders have to purchase their fertilizers and pesticides from private merchants at relatively high prices. One agricultural extension agent shared his perspective as follows:

"20 years ago, in this extension service unit we were 24 employees helping 1200 farmers, now we are only 2 employees. How can we serve all these farmers? Thegovernment stopped employment in this unit in 1995." Agricultural extension agent, Interview No. 3

Furthermore, smallholder farming is a physically arduous profession that often only generates low and fluctuating income. The increasing availability of more attractive and profitable job alternatives, especially for younger and educated people, led to a significant shortage of agricultural labor in many parts of Egypt. This is mirrored in the following statement:

"I have two sons. One is working in Alexandria city and the other one is working as a tok-tok driver. The last one rather prefers to pay me the wage of a field worker than helping me in the field. He always says the work in the field is more exhausting, and he makes better money as a tok-tok driver". Smallholder, Interview No.10

Perceived Changes in Attributes Affecting Wheat Production between 2000 and 2020

This part of the empirical qualitative data collection was aimed at understanding wheat growers' perceptions of changes in attributes affecting wheat production between 2000 and 2020. We applied a five-point Likert scale and asked smallholders to indicate their perception of change (much worse = 1, worse = 2, same = 3, better = 4, and much better = 5). The data show that wheat-growing smallholders perceive a significant deterioration of the extension services, the prices for inputs, the access to subsidized inputs, the profitability and the final price between 2000 and 2020. However, interestingly, they also stated that the access to equipment and the access to seeds improved in this period. Market access and fertilizer access were also seen as being either "the same", "better" or "much better" compared to 2000 for the majority of the smallholders (Figure 6).

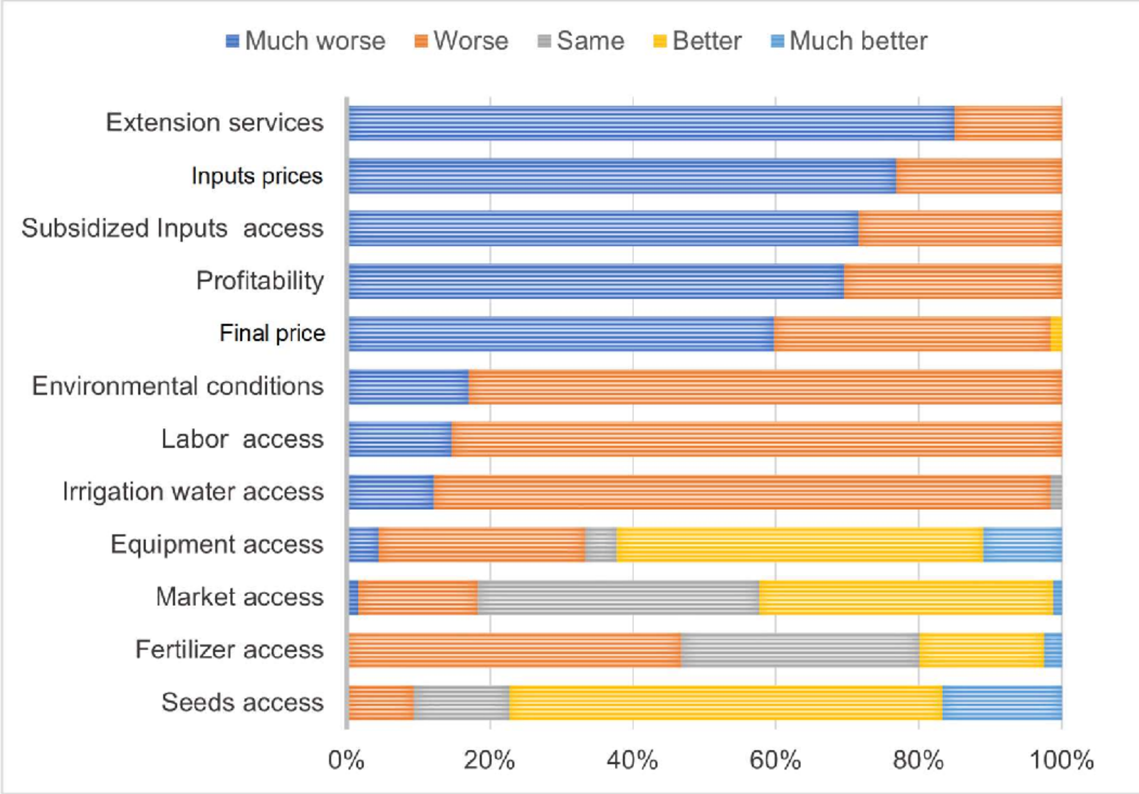

Figure 6. Smallholders' perception of the changes in factors affecting wheat production between 2000 and 2020 (Source: field survey 2020/21 growing season).

4. Discussion

This study shows that the wheat production of smallholders in Egypt depends on a variety of underlying system-immanent and external factors. While smallholdersare the backbone of wheat production in the country, many factors crucially limit their ability and willingness to produce (more) wheat. It is essential to understand smallholders’ perspectives and to tackle these factors in a “bottom-up approach” to increase food security [29], to reduce Egypt’s dependency on wheat imports and unreliable supply chains and to contribute effectively to the “Egypt Sustainable Development Strategy Towards 2030”. Various studies have investigated the factors that influence smallholders’ decisions in crop production and the adoption of agricultural practices [30–33]. All too often, farming systems were categorized into two main categories, subsistence farms and commercial farms, each with seemingly distinct factors and drivers that influence their decision making. In smallholder farming, however, this dichotomy does not reflect reality.

This study investigates the factors that affect wheat-growing smallholders’ decisions in semi-subsistence farming systems. The study found that securing their own wheat supply is the main driver for smallholders to grow wheat. However, the study also shows “regulating screws” that have to be turned to make wheat production more attractive for smallholders. The study found that several economic factors, including wheat price, an earlier declaration of the price that smallholders obtain for their wheat when selling it to the public storage silos, and a more efficient and reliable purchase process at the silos can have a strong impact on the smallholders’ decisions to grow (more) wheat. Smallholders have a strong cultural attachment to and history in growing wheat. Our data show that wheat-growing smallholders usually have decades of experience in growing wheat. Their parcels are small but blessed with fertile soils. Smallholders know the crop wheat—and the socio-economic system around it—extremely well. From one year to another, they could significantly increase the share of their land on which they grow wheat and could increase their productivity—only if the necessaryincentives and inputs are provided, however. With millions of wheat-growing smallholders facing a similar context [34–36], this represents a huge potential that can and should be used to increase domestic production, improve food security, and thus reduce Egypt's dependency from expensive and unreliable wheat imports.

The results also show that there is a strong integration of wheat production and animal husbandry. The findings are consistent with other studies reporting that smallholders in semi-subsistence farming systems often keep animals for milk and meat production, and as a capital and "assurance" assets, use the manure from these animals as fertilizers, and the residues from the crops to feed animals and for their bedding. This integration contributes to a (more) stable access of smallholders to both food and income [36].

Our results show a strong deterioration of the incentives for smallholders in Egypt to produce wheat in the period between 2000 and 2020. This discouraged smallholders from maintaining (or even increasing) the share of wheat on their land and rather to use their land for growing other competing crops. These findings comply with other studies, for example with [37] who observed a reduction in the land used to cultivate cowpeas in Haiti. In general, our findings are consistent with prior research, which has documented that smallholders in many countries of the Global South faced significant challenges in the last two decades with reduced incentives and chances to grow their crops [14]. In contrast, however, other studies highlighted that smallholders were able to significantly increase their crop production, under given circumstances. For instance, contract farming in which smallholders and buyers both agree in advance on the terms and conditions for the production and marketing of certain products, can provide smallholders with better access to markets and technical assistance, and most importantly, less insecurity and exposure to price volatility though predetermined guaranteed prices. This can provide them with the incentives and resources they need to invest in higher productivity of their farms as reported in [38,39].

The adoption of sustainable agriculture practices is impacted by factors such as access to knowledge and training and access to production inputs confirming to [34–36]. This study reveals that wheat-growing smallholders in Egypt perceive a considerable deteriora- tion of the incentives and their capacities to produce wheat sustainably. Similar findings have been reported in other studies conducted in Egypt, also documenting also that prices for production inputs have risen sharply in recent years [14]. Other studies conducted with smallholders in countries of theGlobal South, such as in Ethiopia, have also reported concerns that negatively affected smallholders’ abilities to access production inputs and to increase their yields [31]. Our study also shows that the distribution of (subsidized) inputs to smallholders is often subject to top-down structures and mismanagement. The findings are consistent with previous studies conducted in Egypt [40].

The findings of our study indicate that wheat-growing smallholders in Egypt majority do not feel supported by the governmental extension services. They perceive the extension services to be inadequate, with limited access to information, training, and technical assistance. In the study area, we observed a significant lack of agriculture extension services. This mirrors a general trend in which the total number of agricultural extension staff in Egypt decreased betweenby 2007 and 2018 from 9658 to 2503 [30]. The massive reduction in extension staff and services has hampered the adoption of new technologies and adequate sustainable practices, resulting in reduced yields and lower incomes for smallholders. These findings are consistent with previous studies [30], which showed that extension services are often inaccessible to smallholders, who, however, often produce the bulk of the food and constitute the majority of the rural population.

The significant impact of agricultural policies on smallholder crop production and productivity is shown in many studies [34–36,41]. We can recapitulate that policiesimple- mented by the Egyptian governments since 2000 rather aimed to support the production of export cash crops like citrus and the expansion of agricultural land to the “new lands”. At the same time, they rather neglected the domestic wheat production by smallholders and weakened the productivity and agricultural development in the “old lands”. In conjunction with a population increase from about 70 million in 2000 to about 105 million in 2023 [12] this led to more and more dependency on wheat imports, of which 85% came from Russia and Ukraine in 2021, before the Russia–Ukraine war. The war triggered skyrocketing prices for wheat on the international markets that, coupled with the depreciation of the Egyptian currency, provoked economic, social and food crises. Over the last few decades, highly fertile “old lands” along the River Nile were increasingly used unproductively and were shifted to other agricultural and non-agricultural purposes. Millions of hectares have been converted into land for housing and infrastructure. Other areas formerly used for growing wheat are now used to produce clover. This all brought along losses in the agriculture production revenue, especially with the traditional crops such as wheat [42,43]. Another challenge shown in the findings of our study is the relatively high age of the wheat-growing smallholders. The mean age of the smallholders in the case study is 56 years. The mean age of the whole population in Egypt is, however, only 24.6 years [12]. This over-aging of the people who produce the bulk of the wheat in Egypt is highly problematic. It threatens not only the goal of achieving more domestic wheat self-sufficiency, but the future of the agricultural sector in Egypt as such. Thus, there is a significant need for agriculture policies that make the agricultural sector more lucrative and attractive to the younger generation. Given the long- term neglect of the wheat-producing smallholders and the short-term impacts of the Russia–Ukraine war, food security in Egypt is at high risk. In the medium term,the millions of wheat-producing smallholders in Egypt can play a critical role to prevent millions of Egyptians from (more) poverty and hunger and to avert socio- economic instability, unrest and political conflicts in Egypt. Accordingly, to be more effective and sustainable, agricultural policies need to be based upon the particular needs of wheat smallholders, mainly in the “old lands”. Egypt has very limited cropland, so the policies should aim to increase wheat yields per unit of land in a “vertical approach” mainly in the “old lands”—which can, however, go in parallel with a “horizontal approach” of reclaiming “new lands” for wheat production.

Given the relatively high fertility of soils in the “old land”, the mostly sufficient avail- ability of water, and—not to forget—the long experience and strong cultural attachment of millions of smallholders in and to wheat production, more wheat could be produced in a relatively short time by only adjusting the agronomic practices such as irrigation and inputs managements [44]. This, however, needs substantial and sustained investments and support that should include: (1) providing wheat-growing smallholders with technical sup- port and knowledge through a (re-)strengthened agriculture extension system, (2) paying smallholdershigher prices for their wheat at public silos, (3) providing wheat-growing smallholders with subsidized inputs on time, (4) declaring the wheat prices beforethe growing season, and (5) building a more effective domestic wheat collection system. Each of these activities will be costly. However, when these investments are being made, billions of USD can be saved every year through lower wheat imports, and more socio-economic benefits will be generated through higher domestic economic growth.

5. Conclusions

This study highlights the importance of understanding smallholders' perspectives and underlying factors that influence their ability and willingness to produce (more) wheat. Drawing from nine months of empirical, mixed-method field research in the Nile River Delta, the study found that securing their own food needs and gaining animal fodder are the main factors that influence smallholders' wheat production. Economic factors, including the wheat price declared by the Ministry of Supply and Internal Trade, the time of the price declaration, and the costs of production inputs such as fertilizers, pesticides, and seeds, can, however, have a significant impact on the land share on which smallholders grow wheat, as well as on their productivity, and ultimately on the total wheat production in Egypt. The study reveals the negative impacts of long-term policies and a rundown of the governmental extension system over decades on smallholder decision making, leading to decreased land under wheat and lower productivity. Most smallholders cannot afford production inputs and perceive a lack of access to knowledge and information. The access to knowledge and training has to be guaranteed through an effective extension service. Smallholders need sufficient access to subsidized agricultural inputs to meet the essential nutritional requirements for their crops and achieve a significant improvement in productivity. The study also showed that the factors influencing farmers' decisions to grow wheat or implement innovative practices vary across different areas within the same region. Therefore, it is essential to integrate smallholders' perspectives and needs into the making of targeted policies and interventions, to adapt the tax and subsidy systems with regard to wheat production, to (re-)strengthen the agricultural extension, and to implement them bottom-up accordingly to increase food security and domestic self-sufficiency and to effectively contribute to the "Egypt Sustainable Development Strategy Towards 2030".

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Chapter 7

General discussion and conclusion

General discussion and conclusion

In this section, we will engage in a comprehensive discussion of our research, centered on the hypothesis that improving wheat self-sufficiency in Egypt can be achieved through the refinement of policies and the strategic deployment of agronomic techniques tailored to specific extrapolation domains and social-ecological niches. To test this hypothesis, we delineated three primary objectives in our study, each dedicated to uncovering different facets of the challenge.

Objective 1: Learning from Past Trends

The first objective of our research was to gain insights from historical trends in wheat production in Egypt. Through a retrospective analysis of the nation's agricultural trajectory, we aimed to identify recurring patterns and determinants that have influenced wheat production in the last two decades. By discerning the historical context in which wheat production evolved, we aspired to draw lessons that could inform contemporary efforts to enhance self-sufficiency.

Our findings in Chapter 4 underscore the importance of recognizing the cyclical nature of wheat production in Egypt, influenced by factors such as climatic conditions, technological advancements, and economic shifts. The historical perspective revealed both successes and challenges, shedding light on the need for adaptive policies and targeted interventions.

Objective 2: Quantifying Performance Attributes

The second objective focused on quantifying key performance attributes within Egypt's diverse wheat-growing environments. This quantitative approach aimed to provide a nuanced understanding of the conditions that govern wheat production. Chapter 5 presented our detailed assessments, highlighting the variations in performance across regions and the impact of factors such as soil quality, irrigation, and agronomic practices. Our analysis revealed significant disparities in performance attributes, suggesting that a one-size-fits-all approach to policy and agronomic interventions would be inadequate. Instead, our findings emphasized the importance of region-specific strategies to optimize wheat production in Egypt.

Objective 3: Uncovering System Inherent Determinants and External Pressures from smallholder perceptions

Objective 3 in chapter 6 underscored the socio-ecological dimensions entailing the consumption of wheat-based *baladi* bread, a staple in the diet of millions of Egyptians. This segment of the study sought to determine, both internal and external, that exerts influence upon the decisions undertaken by smallholder farmers to either increase or curtail wheat cultivation area. The findings accentuated regional disparities within the expanse of the Nile River Delta, thereby accentuating the exigency of bespoke interventions tailored to the idiosyncrasies of distinct social-ecological niches.

Synthesis and Confirmation of Hypothesis

In reflection of our findings in Chapters 4, 5, and 6, it is evident that our research has significantly contributed to affirming our initial hypothesis. The historical analysis illuminated the cyclical nature of wheat production and the importance of adaptive policies. The quantification of performance attributes underscored the necessity of tailored interventions based on regional disparities. Lastly, the exploration of system-inherent determinants and external pressures emphasized the complexity of the agricultural landscape.

In essence, our study supports the hypothesis that increasing wheat self-sufficiency in Egypt necessitates an integrated approach, harmonizing policies and agronomic strategies while considering the multifaceted determinants influencing production. This discussion serves as a prelude to the ensuing "General Discussion and Conclusions" section, wherein we consolidate these findings and propose a comprehensive framework for achieving enhanced wheat self-sufficiency in Egypt, building upon the evidence-based insights garnered from our multifaceted investigation.

Our comprehensive analysis underscores the pivotal role of addressing constraints and fostering resilience in Egypt's wheat production landscape. This involves recognizing the historical context, embracing region-specific strategies, and considering both internal and external factors influencing smallholder decisions. The ultimate goal is to reduce Egypt's reliance on capricious wheat imports, enhance food security, and promote agricultural sustainability in the face of a growing population and global uncertainties.

Chapters 4, 5, and 6 of this thesis embarked upon a detailed exposition of the findings and prescriptive recommendations, which collectively corroborate and substantiate the hypothesis enunciated in this study.

Conclusion

Egypt, with a population exceeding 104 million people, is the most populated country in the Arab world and the third most populous in Africa. The importance of wheat within the Egyptian diet as a staple food crop is evident, with wheat- based products, mainly subsidized *baladi* bread, comprising a significant proportion of daily caloric and protein intake for its citizens. Despite the country's strategic geographical advantage along the Nile River and Delta, Egypt relies heavily on wheat imports. This reality has solidified its status as the world's largest wheat-importing nation. The nation's political stability is intricately intertwined withthe availability and affordability of these wheat products, a notion made starkly evident by the socio-political upheaval witnessed during the 2011 Egyptian revolution and the bread riots in 1977.

Declining Self-Sufficiency and Complex Factors In the context of Egypt's wheat production landscape, the first part of the study spanning the years 2000 to 2020, unveiled a concerning trend. Despite achieving comparably high wheat yields per unit of land, the nation's self-sufficiency in wheat witnessed an alarming two percent annual decline. This dwindling self-sufficiency trajectory, attributed to many intertwined factors, has rendered Egypt's quest for domestic wheat production increasingly elusive.

The constraints of limited arable land and water resources have necessitated a delicate balancing act between wheat cultivation and competing cash crops such as broad beans and clover.

The dynamic nature of wheat production, characterized by fluctuations in cultivated area, production, and yields, has created an intricate web of challenges. Furthermore, the shifting landscape of policies and governmental support has impacted wheat producers, resulting in diminishing incentives and attractiveness for wheat cultivation. The research underscores the need for strategic interventions to revitalize wheat cultivation, particularly among smallholders who have faced significant constraints such as input shortages, inadequate prices, climate change, and the continual increases in input costs. The projected trajectory points to an exacerbation of reliance on wheat imports due to an expanding population, ineffective policies, climate change and dwindling resources.

Sustainable Practices and Empowering Smallholders Elevating domestic wheat production assumes paramount significance in mitigating the economic strain associated with importing wheat and ensuring resilience against global supply disruptions. A comprehensive approach rooted in sustainable agricultural practices has been advocated as a potential remedy. Key among these practices are sustainable irrigation and fertilization strategies that have the potential to substantially boost yields and overall domestic wheat production. Two strategies emerge as promising avenues: first, a strategic shift in land allocation by partially substituting berseem clover with wheat, thereby expanding the area dedicated to wheat cultivation; second, the implementation of effective and sustainable agronomic practices that bridge yield gaps while bolstering farmers' income. However, smallholder farmers, a critical component of Egypt's agricultural landscape, encounter multifaceted challenges spanning limited access to knowledge, technology, markets, and credit facilities. The efficacy of such comprehensive strategies hinges on addressing these challenges and fostering an enabling environment for smallholders to thrive.

Integrating Smallholders' Perspectives and Policy Implications A granular understanding of the perspectives and underlying factors shaping smallholders' decisions concerning wheat cultivation has surfaced as an essential component of policy formulation. Empirical field research spanning the Nile River Delta region underscores that securing food needs and obtaining animal fodder are central motivations for smallholders' engagement in wheat production. The economic dimensions, including wheat prices, the timing of price declarations, and input costs, wield substantial influence over their decisions and productivity. A gradual erosion of government extension services and long-standing policies has significantly dampened smallholders' incentives for wheat cultivation, contributing to a decline in both cultivation area and productivity. To address this, the last part of the study emphasizes the indispensable role of an effective extension service in facilitating knowledge transfer and the timely provision of subsidized inputs. Acknowledging the diversity of factors influencing farmers' decisions, the research underscores the imperative of integrating localized perspectives into policy frameworks, adapting taxation and subsidy mechanisms to bolster wheat production, and revitalizing the agricultural extension system.

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