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Prediction of Wheat Storage Process Under Climate Change: A Case Study of Northwestern Regions of Tunisia

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ABSTRACT

In this work, a simulation of the climate change impact on the wheat grain storage process in Northwestern regions of Tunisia was investigated based on grain aeration systems. This simulation was conducted by implementing the software package called Zephyrus for a period from 2041 to 2070 during storage season from the 01st of July to the 30th of November. The model estimates grain moisture content, grain temperature, and dry matter loss. The results showed a significant potential of the Zypherus strategy to maintain the grain moisture content around 12.2± 0.2% w.b. and to reduce grain temperatures from 35°C to 24 ± 1.5°C inside the silo. Consequently, under these values, the wheat storage process is considered safe and preserves wheat quality during the simulated storage period. Moreover, the wheat dry loss matter was about 0.8% during the whole storage period for each simulated year (approximately 0.15% per month).

INTRODUCTION

Climate change predictions and their repercussions have become an increasing issue, that has interested considerably the scientific community. In the previous century, global mean temperatures have risen by more than 0.5 °C (IPOC, 2007), and the Intergovernmental Panel on Climate Change (IPCC) predicts that they will rise by 1.1 to 5.4 °C by 2100 (Bale *et al.*, 2002). In the African continent, the average temperature will increase by more than 3°C by 2080 (Asafu-Adjaye, 2013). Of its importance around the world and particularly in African countries, agriculture was the first sector to be affected by the climate-changing trends (Dinar *et al.*, 2012; Adams *et al.* 1990) as like as world food production (Lobell *et al.*, 2011). Climate change will have significant impacts on plant growth, agricultural productivity, and trends in the world's food supply (Parry *et al.*, 2005); as a result, it will all have a substantial impact on food security worldwide. To deal with the situation, numerous mitigating measures are being developed (Nayar, 2009). One of these was safe food grain storage which is considered a way to achieve food security (Jayas, 2012) and adapt to the global changing climates (UNEP, 2010), particularly during times when agriculture is ineffective. Grain can be kept in silos, warehouses, bags, containers, conventional storage buildings, or other predetermined units (Moses *et al.*, 2015). The farmer, the miller, the importer, and the government can store grain at various points along the food supply chain for different reasons. Their main objective is to satisfy customer demand for food grains. The stored grain is considered an artificial ecosystem that is constantly interacting with not only abiotic variables like temperature, relative humidity, intergranular CO2 levels, and moisture content but also with biotic ones like insect pests, fungi, mites, and rodents. With time, interactions continue, and unfavorable ones lead to grain degradation (Moses *et al.*, 2015). Thus, Physical storage conditions, as well as different pests and illnesses that appear during the post-harvest phases of agricultural commodities, have a significant impact on product quantity and quality (Rees, 2004; Dowell & Dowell, 2017). To forecast mass and heat transfer in grain bins during the aeration process, some researchers have created and tested mathematical models. These models have been used to assess grain moisture content, temperature, and dry matter loss, making them useful tools for more advanced control strategies and for improving monitoring processes. (Frank & Howard,1995; Canchun *et al.*, 2001; Devilla, 2002; Khatchatourian & Oliveira, 2006; Lopes *et al.*, 2008).

Otherwise, the loss in quality and quantity of grains during the storage process compels governments to import grains to satisfy citizen demand at a significantly higher cost. However, if grains were protected and well stored, demand for imports could be decreased, saving significant foreign cash. Reducing losses for grain-exporting nations should increase income for the nation and its farmers, raising the standard of life for its population. Therefore, a national strategy to provide a suitable infrastructure over several years and a suitable education plan via effective extension services for grain storage managers can greatly boost (Jayas, 2012).

In Tunisia, grain storage, in particular wheat storage, is an important process to ensure food security (Lakhoua, 2019). The wheat sector has a significant gap between local demand and production (Chebil *et al.*, 2015). Hence, nearly half of the wheat consumed during the past few decades was imported annually by the Tunisian government. Then, the cost of importing wheat is rising

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in tandem with its price on the global market, which raises the number of government subsidies given to the industry, particularly during the global "food crisis" period (Laajimi *et al.*, 2013). As a result, increasing wheat productivity and then managing the wheat storage process properly in Tunisia became essential for raising the wheat self-sufficiency ratio (Chebil *et al.*, 2014; Lakhoua, 2019). In addition, Tunisia is one of the north African countries which is affected by the climate-changing trends and many studies in the literature have dealt with the prediction of Tunisian wheat production under climate change (Lhomme *et al.*, 2009; Bahri *et al.*, 2019) but there is a lack of studies showing the impact of climate change on wheat storage process. Hence, the objective of this work is to study the future potential of grain aeration during the storage process under climate change conditions in Tunisia. This study presents the impact of temperature variability on the physical properties of stored wheat using a process simulation and real data acquisition.

MATERIALS AND METHODS

Data and Climate Scenario

To describe the local effects of anticipated ambient air temperature and relative humidity on the future of the ambient aeration storage process, we used Regional Climate Models (RCMs). RCMs are frequently used to offer more specific information for a specific geographic area. RCMs integration is usually performed at a horizontal resolution of 10-50 km over a specific region of interest. They can offer detailed temperature and moisture information for a particular region by combining explicit resolution techniques and parameterizations tailored to greater resolutions (IPCC, 2013). In this study, the regional climate models developed by the Swedish Meteorological and Hydrographic Institute (SMHI) were used to provide an hourly prediction of temperature and relative humidity of the ambient air of the north-western regions of Tunisia for 30 years period from 2041 to 2070. The scenario RCP 4.5, often known as a moderate scenario, was used to assess the margin of availability of favorable hours for grain aeration.

Storage Process Model

Simulations were conducted by software created based on the model presented by Thorpe (2001) and validated by Lopes *et al.* (2015). The program enables the simulation of the aeration process in various air conditions. In this research, the aeration of wheat grains during the storage process was controlled by the Zephyrus strategy described by Lopez & Steidle Neto (2019). This aeration controller is based on the forecasting of air velocity and variations in temperature and moisture while air is circulated through a grain bulk. This work focused on wheat grain because it is the most grown cereal in Tunisia. It occupies more than 50% of the cereal area and contributes to more than 40% of the cereal production (MA, 2012). Additionally, the studied region (Northwestern region) is one of the major producers and consumers of this crop (Chebil *et al.*, 2015). The input data for the simulations were initial grain temperature (35 °C, the average ambient temperature in July when starts the storage process of wheat grain in Tunisia), moisture content (13 % w.b.), grain bulk density (763 Kg m−3, durum wheat), geometric characteristics of the bin (diameter 10 m, height 18 m), aeration airflow(6 m3 h-1 t-1), the local atmospheric pressure and a file containing the hourly temperatures and relative humidity of the ambient air for the storage period from July 01 to November 30 for each year according to the SMHI models and according to the RCP 4.5 scenario for the period 2041-2070. Data of ambient dry bulk temperature and relative humidity for the Northwestern regions of Tunisia were obtained from the website http://digilib.icpac.net/

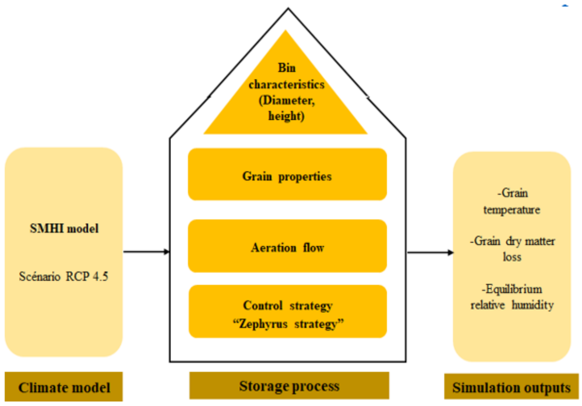


Figure 1: Schematic image of the storage simulation process.

RESULTS AND DISCUSSION

Moisture content

Numerous factors, including soil temperature, solar radiation, ambient air temperature, and grain temperature, have an impact on the moisture content of grains (Chang *et al.*,1994).

During storage, the grain must be shielded from climate variability, insects, and the development of microbes to maintain its quality. The variations in air temperature and solar radiation from one season to another generate temperature gradients in the grain and thus move moisture from warmer to cooler grain areas. Then, the moisture buildup in a specific grain area encourages the growth and development of fungi and insects (Hunt & Pixton, 1974; Chang *et al.*, 1994).

The study conducted by Fan *et al.* (1961) on the water diffusion in different varieties of wheat showed that the expression of the diffusion coefficient of moisture in wheat is a function of the reciprocal of absolute temperature. Jayas (2012) reported that storage at high moisture content and high temperature promotes quick spoilage of the stored grain. Hence, to store safely wheat grains under tempered weather the moisture content should be around 12-13% w.b.

Figure 2 presents predicted wheat grain moisture contents for the studied years. For all of the years under study,

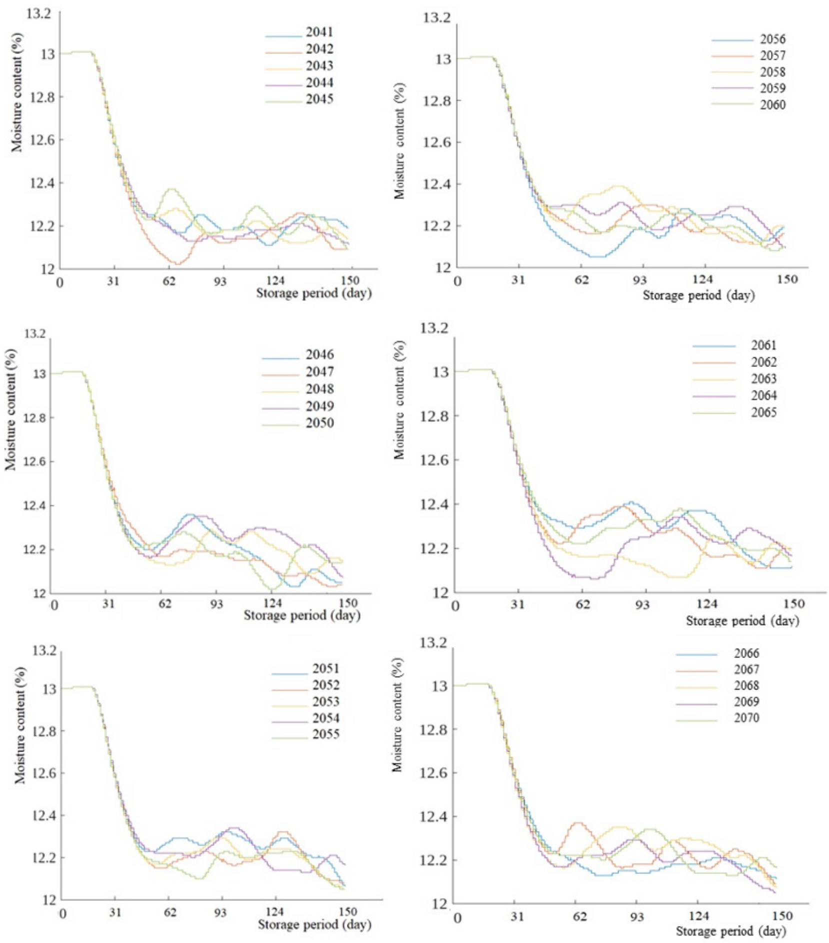


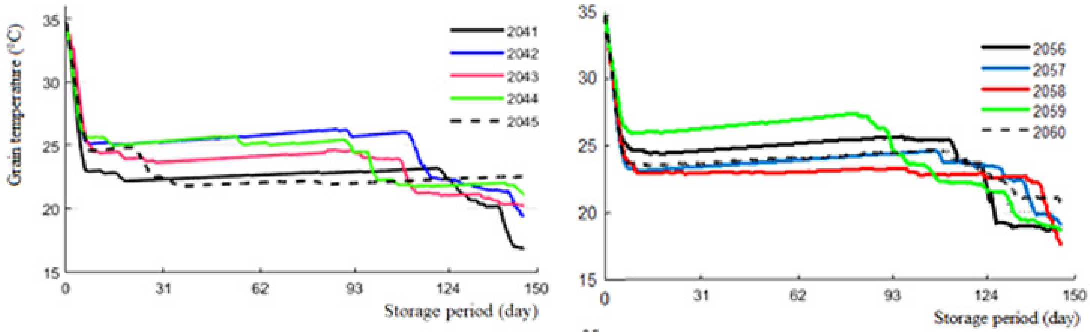
Figure 2: Simulated wheat grain moisture content when using the Zephyrus strategy for three future decades years.

safe moisture contents were effectively maintained. All simulated moisture contents ranged from 13% to 12.2± 0.2% w.b. for the whole study period, which corresponds to equilibrium relative humidities between 65.8% and 62 ± 0.2% when taking temperatures between 35 °C and 24±1.5°C (Figure 3) into account. According to Weinberg *et al.* (2008) and Jayas (2012), under these circumstances, the growth of microorganisms can be effectively stopped.

Grain Temperature

Figure 3 presents the evolution of the average bulk grain temperatures throughout the whole simulated period. As shown, the Zephyrus system reduced grain temperatures from 35°C to around 24°C from July to November for each studied year.

For the first decade of years (2041-2050), the grain temperatures decrease after almost 7 days from the beginning of the storage process from 35°C to 24±1°C then this value was maintained until the end of the month October. From this later the grain temperatures were slightly decreased (22°C) which can be explained by the decrease of air ambient temperature in the Autumn season. For the two other decades of years (2051-2060 and 2061-2070), the same behavior was observed with a little bit of difference in temperature values with 25±1°C for the maintained grain temperatures and then 20±1°C at the end of October.



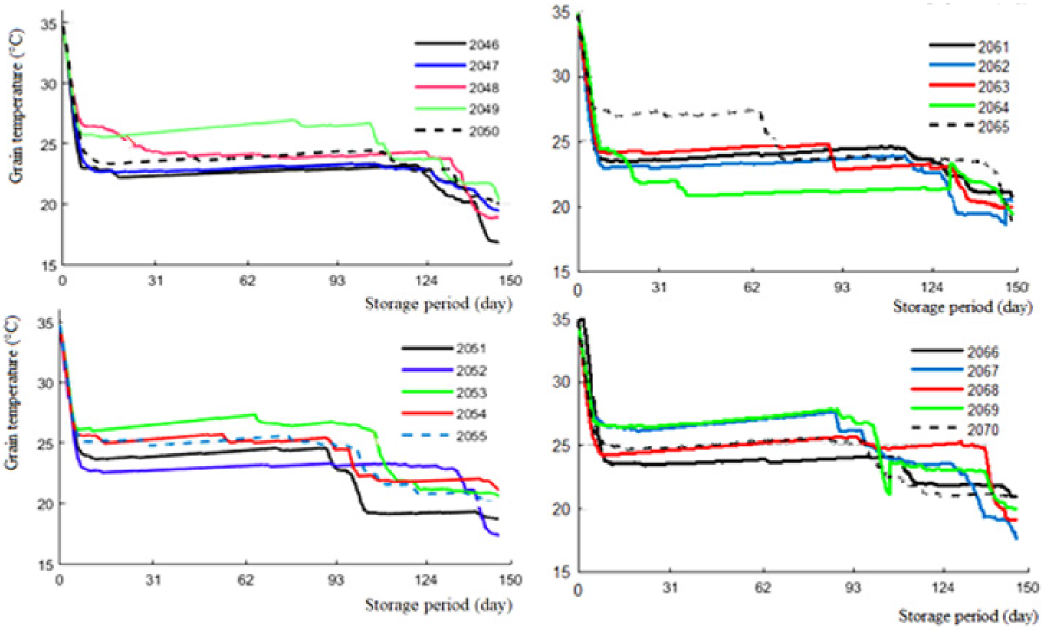


Figure 3: Simulated wheat grain temperature when using the Zephyrus strategy for three future decades years.

Dry matter loss

Wheat grain dry matter loss is influenced by moisture content, temperature, mechanical damage, type and severity of microfloral infection, and insects. It is equally linked to the degree of grain respiration and CO_2 production (Garcia-Cela *et al.*, 2018; Meneghetti *et al.*, 2021). Figure 4 shows simulated dry matter loss of stored wheat grain for each year of the three decades years (2041 - 2070). The behaviors of the three decades years were similar. About 0.8% of dry matter loss was observed for

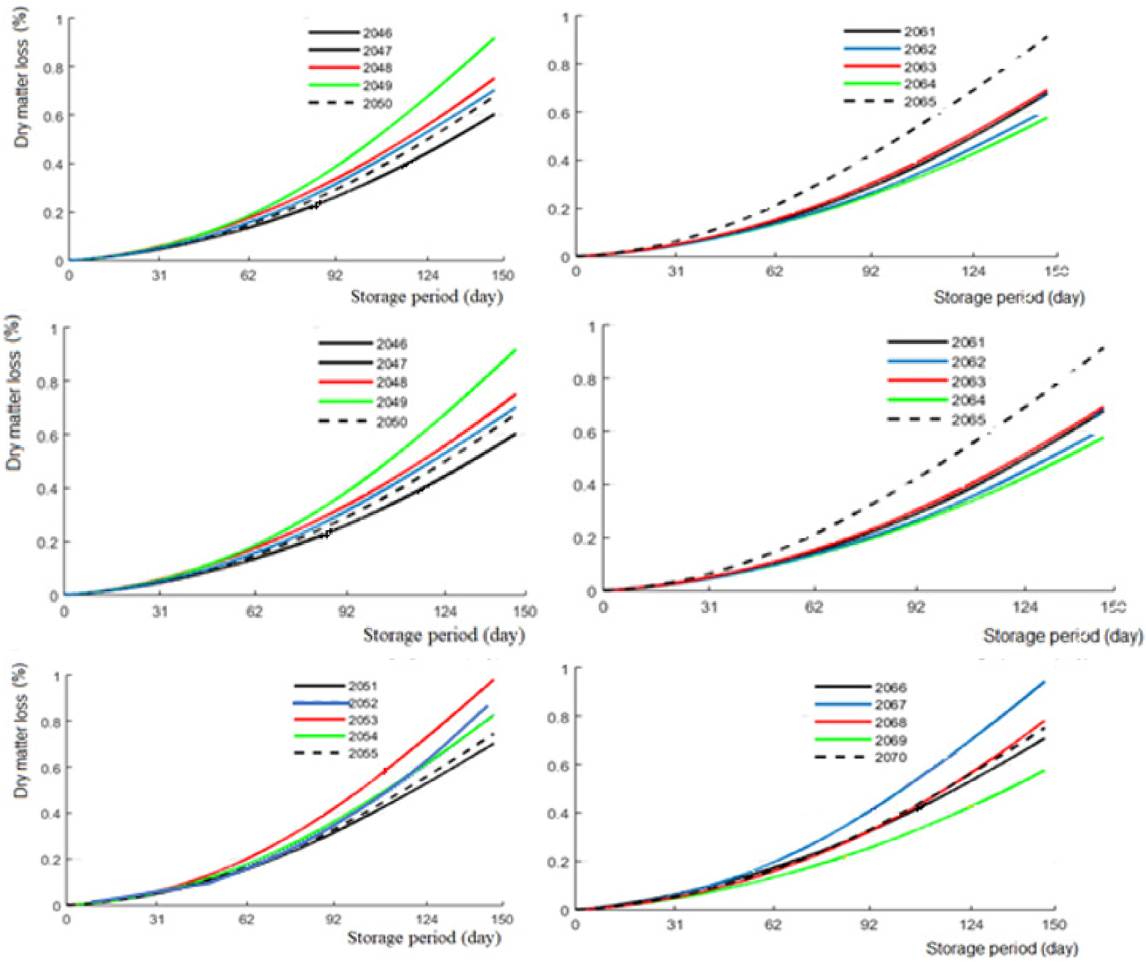


Figure 4: Simulated dry matter losses when using the Zephyrus strategy for three future decades years.

the whole storage period with about 0.15% per month in each year. This result is confirmed by the authors Polat (2013) and Kalsa *et al.* (2019) who reported in their works conducted on the wheat storage process in Turkey and Ethiopia respectively, a 0.11% dry matter loss per month.

CONCLUSION

The quality of wheat grains during the storage process is mostly affected directly or indirectly by the temperature and moisture content. The prediction of these later for a period of 30 years from 2041 to 2070 in Northwestern regions in Tunisia using the Zephyrus strategy was investigated. The results showed the safe storage of wheat grains for the whole period. The two major factors grain temperature and moisture contents were maintained successfully around 24 ± 1.5°C and 12.2± 0.2% w.b. respectively due to the aeration control strategy. This later also makes the dry matter loss amount not significant during the whole simulated period of years with a percentage of 0.15% per month in each year.

Under the climate-changing conditions and the armed conflict between most cereals producers and exporters countries Russia and Ukraine, Tunisia has to enhance research and development in wheat grains storage techniques to ensure the wheat's self-sufficiency ratio. This study is the first one conducted on the prediction of wheat grains storage under climate change context in Tunisia in which results can be improved and completed by comparison with others models of prediction and can be extended to study the potential of the wheat grains storage process in other regions in Tunisia.

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