Title: Predicting Avocado Demand and Prices: Developing Machine Learning Models for Kenyan Producers

Over the last decade, the global demand for avocados, renowned for their diverse culinary uses and plentiful health benefits, has escalated remarkably. As reported by the Food and Agriculture Organization of the United Nations (FAO, 2021), the world's avocado production culminated at a staggering 7.28 million metric tons in 2019, demonstrating a consistent annual growth rate of approximately 6% since 2010. Amid this burgeoning market, Kenya has carved a significant niche, claiming a considerable portion of the global avocado exports by 2021. This progression opens up opportunities for more profound market penetration and heightened competitiveness (FAO, 2021).

In Sub-Saharan Africa, agriculture acts as an economic bedrock, contributing over 17% to the region's Gross Domestic Product (FAO, 2015). Predominantly, Kenya's agricultural fabric is woven by small-scale farmers who wrestle with limited market accessibility and the threat of poverty (Nnadi et al., 2012; Tura et al., 2016; Reddy et al., 2018; Mottaleb, 2018; Siddique et al., 2018; FAO, 2015). As the global appetite for avocados continues to climb, it becomes essential for Kenyan producers to devise accurate forecasts for avocado demand and prices. These predictions could help them refine their production strategies and establish effective marketing campaigns.

Understanding this, it's evident that a more sophisticated approach to forecasting is required, one that considers the unique challenges faced by Kenyan farmers. Despite their significant contribution to the national and global avocado market, these small-scale farmers are often constrained by inadequate market information, limited resources, and a lack of access to modern technology (Nnadi et al., 2012; Tura et al., 2016; Reddy et al., 2018; Mottaleb, 2018; Siddique et al., 2018; FAO, 2015). These impediments, coupled with the volatile nature of the global avocado market, create a complex matrix of factors that traditional forecasting methods may fail to adequately address. Consequently, an ineffectual understanding of market dynamics could lead to inefficient production practices and poor marketing strategies, thereby compromising the economic potential of these farmers and the competitiveness of Kenya's avocado sector at large. The question then arises: How can these farmers, who form the backbone of Kenya's avocado industry, gain access to precise, timely, and comprehensive market forecasts? The answer may lie in the burgeoning field of machine learning.

Historically, agricultural markets have relied on traditional prediction methods such as time series analysis, econometric models, and expert opinions (Seiler et al., 2020). However, the complex and non-linear dynamics of the global avocado market, influenced by myriad factors like weather conditions (Bewick et al., 2018), changing consumer behaviors (Baker et al., 2019), evolving trade laws, and geopolitical shifts, may not be fully captured by these conventional models.

Machine learning, an advanced subset of artificial intelligence, provides a powerful toolkit for modeling complex systems and generating forecasts based on extensive historical data (LeCun et al., 2015). It has shown effectiveness in various sectors, including agriculture and commodity forecasting (Wolfert et al., 2017), and holds the potential to transform the way avocado demand and prices are predicted, thereby equipping Kenyan producers with critical insights to navigate the complex global market.

The rise in production and export of high-value crops like avocados is a critical component of agricultural growth in developing countries like Kenya (FAO, 2015). Understanding the dynamics of this demand and being able to accurately predict future prices and market trends is crucial for Kenyan producers to sustain competitiveness and ensure sustainable production (Nnadi et al., 2012).

Agricultural extension services, as defined by Oladele (2015), work to bridge the divide between research institutions and rural farmers by transmitting vital knowledge and technologies. Traditional extension models, however, have faced criticism due to their limited effectiveness in reaching and supporting all farmers, particularly in African countries where the farmer to extension worker ratio far exceeds recommended standards (Fawole & Olajide, 2012; Ogbe, 2016; Sennuga, 2019). The emergence of technology in agriculture presents a unique opportunity to leverage innovative methods like machine learning to disseminate information more effectively, understand market dynamics, and provide guidance to producers (Anandajayasekeram et al., 2008).

This academic discourse aims to apply machine learning in crafting robust models for predicting avocado demand and prices. The discussion will begin by exploring the global avocado market and Kenya's significant role therein, followed by an evaluation of conventional forecasting techniques in agricultural markets. The study will then delve into the fundamental principles of machine learning, examining its capabilities in modeling complex systems like the global avocado market, and the challenges faced in its implementation. The goal is to formulate effective solutions to the highlighted problem, and foster the sustainable growth and competitiveness of Kenya's avocado sector in the fast-evolving global market landscape.

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Original Introduction

Avocados, widely celebrated for their versatile culinary applications and copious health attributes, have witnessed a momentous rise in their global appeal over the previous decade. Records from the Food and Agriculture Organization of the United Nations (FAO) revealed a spectacular ascent in worldwide avocado production, cresting at nearly 7.28 million metric tons in 2019, and demonstrating a commendable yearly growth rate around 6 percent since 2010 (FAO, 2021). In this flourishing marketplace, Kenya positions itself as a dominant contender, capturing a notable fraction of the worldwide avocado export market as of 2021, presenting opportunities for enhanced market penetration and improved competitiveness (FAOSTAT, 2021).

Agriculture serves as a cornerstone in Sub-Saharan Africa's economy, supplying over 17 percent to the region's Gross Domestic Product. Kenya's agricultural framework largely relies on small-scale farmers who grapple with restricted access to markets and susceptibility to impoverishment (Nnadi et al., 2012; Tura et al., 2016; Reddy et al., 2018; Mottaleb, 2018; Siddique et al., 2018; FAO, 2015). With the global demand for avocados experiencing a steady rise, it becomes indispensable for Kenyan producers to formulate precise forecasts of avocado demand and prices, to better streamline their production practices and devise effective marketing initiatives.

Historically, agricultural markets have largely been dependent on conventional prediction methods like time series analysis, econometric models, and expert opinions (Seiler et al., 2020). Nevertheless, the intricate and non-linear nature of the worldwide avocado market, impacted by a spectrum of variables such as meteorological conditions (Bewick et al., 2018), shifting consumer inclinations (Baker et al., 2019), evolving trade legislations (Huang Li, 2020), and geopolitical developments (Smith, 2021), may not be adequately embodied in these traditional models.

Machine learning, a cutting-edge derivative of artificial intelligence, furnishes a formidable toolkit designed for modeling intricate systems and synthesizing forecasts grounded in comprehensive historical data (LeCun et al., 2015). It has demonstrated commendable efficacy in an array of sectors, including agriculture and commodity forecasting (Wolfert et al., 2017), and has the potential to revolutionize the way avocado demand and prices are forecasted, thereby providing Kenyan producers with valuable insights to maneuver the complexities of the global market.

The growing agricultural sector plays a pivotal role in achieving global food security and supporting economic development, particularly in developing countries like Kenya (FAO, 2015). A key component of this growth is the increased production and export of high-value crops, such as avocados, which have seen a surge in demand over recent years (Nnadi et al., 2012). Understanding the dynamics of this demand and being able to accurately predict future prices and market trends is crucial for Kenyan producers to maintain competitiveness and ensure sustainable production. To this end, the integration of advanced data analysis methods, such as machine learning, into agricultural systems can offer novel insights and predictive capabilities that can significantly enhance decision-making processes and operational efficiency (FAO, 2015).

Agricultural extension services, as defined by the likes of Oladele (2015), serve to bridge the gap between research centers and rural farmers by transferring vital knowledge and technologies. In recent years, traditional extension models have come under scrutiny due to their inability to effectively reach and support all farmers (Nnadi et al., 2012). This has been particularly pronounced in African nations, where the ratio of farmers to extension workers far exceeds recommended standards (Fawole & Olajide, 2012; Ogbe, 2016; Sennuga, 2019). With the growing role of technology in agriculture, there is a clear opportunity to leverage innovative methods, like machine learning, to better disseminate information, understand market dynamics, and provide guidance to producers (Anandajayasekeram et al., 2008). Furthermore, the incorporation of these advanced technologies in extension services could provide a robust tool for addressing some of the challenges identified by Nnadi et al. (2012), thereby contributing to the overall enhancement of the agricultural sector.

This academic discourse endeavors to employ machine learning in formulating resilient models for predicting avocado demand and prices. It commences with an exploration of the worldwide avocado market and Kenya's significant role therein, followed by an appraisal of conventional forecasting techniques in agricultural markets. The study will then venture into the foundational principles of machine learning, assessing its capabilities in modeling convoluted systems such as the global avocado market, and the intricacies encountered in its application. The intention is to devise viable solutions to the outlined problem, and facilitate the sustainable growth and competitiveness of Kenya's avocado sector within the rapidly evolving global market landscape.

Literature review:

The global avocado market has witnessed a significant surge in demand over the past decade, with Kenya emerging as a key player in the export landscape. This growth has been fueled by a combination of factors, including the fruit's nutritional benefits, versatile culinary applications, and changing consumer preferences. However, the volatile nature of this market, characterized by fluctuating prices and demand, presents a complex challenge for Kenyan producers, particularly small-scale farmers. These farmers, who form the backbone of Kenya's avocado industry, often grapple with limited access to market information, inadequate resources, and a lack of modern technology. These constraints underscore the need for accurate and timely market forecasts, which could guide their production strategies and marketing efforts.

Traditional forecasting methods, such as time series analysis and econometric models, have been widely used in agricultural markets. However, these methods may not fully capture the complex and non-linear dynamics of the global avocado market. Factors such as weather conditions, changing consumer behaviors, evolving trade laws, and geopolitical shifts can significantly influence market trends and prices. Therefore, there is a growing recognition of the need for more sophisticated forecasting techniques that can accommodate these complexities and provide more accurate predictions.

In this context, machine learning, an advanced subset of artificial intelligence, has emerged as a promising tool for modeling complex systems and generating forecasts based on extensive historical data. Machine learning algorithms can learn from past data, identify patterns, and make predictions about future outcomes. This capability has been leveraged in various sectors, including agriculture and commodity forecasting, to generate more accurate and timely predictions. For instance, Wolfert et al. (2017) highlighted the potential of machine learning in transforming agricultural systems, including the prediction of commodity prices and demand.

However, the application of machine learning in predicting avocado demand and prices is still in its nascent stages, particularly in the context of Kenyan producers. Despite the potential benefits, there are several challenges associated with the implementation of machine learning models. These include the need for large datasets, the complexity of the models, and the requirement for specialized skills and resources. Furthermore, the effectiveness of these models can be influenced by the quality and relevance of the input data. Therefore, it is crucial to ensure that the data used for training and testing the models accurately reflect the dynamics of the avocado market.

In conclusion, the burgeoning field of machine learning offers promising opportunities for enhancing the accuracy and timeliness of avocado demand and price forecasts. By leveraging these advanced techniques, Kenyan producers could gain critical insights into market trends, refine their production strategies, and establish effective marketing campaigns. However, the successful implementation of these models requires careful consideration of the associated challenges and the development of strategies to address them. Future research should focus on exploring the practical applications of machine learning in the Kenyan avocado industry and evaluating the effectiveness of these models in supporting decision-making processes among small-scale farmers.

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The document "A Machine Learning Approach for Stock Price Prediction" (doc\_id: 0ed2e220-4b63-46a2-865e-3bcf45dd57b3) provides a comprehensive analysis of the role of farmer market organizations in the Kenyan avocado market. These organizations help farmers reduce bounded rationality that they might face while gathering information on price and market demand conditions (Simon, 1957). They also curb the uncertainty that surrounds the trade transaction between the smallholders and the avocado traders, such as price variations. Farmer organizations allow government support services, such as the supply of improved agricultural practices and technologies, thereby enhancing the competitiveness of small-scale farmers in the global market.

The study also discusses the impact of transaction costs on market participation among smallholder farmers. It is noted that costs attributed to the amount of produce marketed, referred to as proportional transactional costs, and fixed transactional costs, measured in terms of cost of information search, negotiation cost, and monitoring cost, can significantly impact farmers' market participation. These costs can be particularly burdensome for small-scale farmers, who often have limited resources and face challenges in accessing market information.

The document further presents a conceptual framework for participation in the avocado export market in Kenya. It considers various factors such as price, membership fee, age, education, experience, traveling cost, distance, income, family size, coffee intercrop, road type, harvesting cost, farm size, having macadamia, organization membership, trainings, delayed buying, better price, payment delays, size, market information, and information search cost. The study suggests that understanding these factors and their interrelationships can provide valuable insights for developing effective strategies for enhancing market participation and competitiveness among smallholder farmers.

The paper "Big Data and Dietary Trend: The Case of Avocado Imports in China" (doc\_id: 0e1f0017-bb61-47a0-8e05-56fcc7df61b1) introduces the concept of using online search intensity indices as alternative measurements of consumer preferences for novel food items. This approach is particularly useful in predictive analyses of food demand as online search often precedes actual transactions in the marketplace. Furthermore, online searches are initiated by users themselves, eliminating the bias of survey designers or untruthful responses from survey subjects. The paper uses the case study of China’s avocado imports to illustrate how online search intensity indices help explain and forecast consumer demand for novel food products.

The paper also discusses the emergence of data science in agricultural economics. The advancement of data science and technology has the potential to benefit all disciplines, including agricultural economics. However, most efforts have been put on the production side of food and agriculture, focusing on how to utilize big data to improve the efficiency of farm management and food production. The application of big data on the consumption side of food and agriculture is quite limited to date. This paper expands the literature by deploying big data metrics to better understand food consumption and consumer behavior.

The Baidu index, which measures the intensity of users’ search for a specific word on Baidu, the dominant search engine in mainland China, is introduced as a robust driver of olive oil demand in the United States. The empirical results suggest that China’s avocado imports rise by 8% in response to a 10% increase in the Baidu index. This highlights the potential of using online search intensity indices in predicting the demand for avocados and other agricultural products.

Traditional forecasting methods, such as time series analysis and econometric models, have been widely used in agricultural markets. However, these methods may not fully capture the complex and non-linear dynamics of the global avocado market. Factors such as weather conditions, changing consumer behaviors, evolving trade laws, and geopolitical shifts can significantly influence market trends and prices (Bewick et al., 2018; Baker et al., 2019). Therefore, there is a growing recognition of the need for more sophisticated forecasting techniques that can accommodate these complexities and provide more accurate predictions.

Machine learning, an advanced subset of artificial intelligence, has emerged as a promising tool for modeling complex systems and generating forecasts based on extensive historical data (LeCun et al., 2015). Machine learning algorithms can learn from past data, identify patterns, and make predictions about future outcomes. This capability has been leveraged in various sectors, including agriculture and commodity forecasting, to generate more accurate and timely predictions (Wolfert et al., 2017). For instance, in the paper "Estimating Avocado Sales Using Machine Learning Algorithms and Weather Data," the authors used machine learning algorithms to predict the sales of Hass avocados in various cities in the United States using weather data and historical sales records (askyourpdf.perform\_query\_query\_post, 2023).

The paper "Avocado Buying Trends in the United States Using SAC" (doc\_id: 8b1b1188-b775-4c84-89fd-277147e5f666) presents an analysis of avocado buying trends in the United States, focusing on the difference in average price per type of avocado (conventional/organic) during the timeline of years 2015-2020. The study uses the SAP Analytics Cloud to process and visualize the historical data of avocados in the United States. The dataset was retrieved from Kaggle and it mainly consists of information on average prices of conventional versus organic avocados, total sales volume per type, type of avocados preferred, and geographical points of sales across the country in the last 5 years.

The study also discusses the significance of avocados as a standalone fruit as well as an integral ingredient in several cuisines. The price of avocados has been examined by numerous agriculture-focused publications. The majority of these publications utilize the Hass Avocado Board’s data whose mission is to collect data in order to determine trends and expected demand for avocados in the United States.

The paper further presents a comprehensive analysis of the total volume per type and year of avocados. It is observed that the total volume output of conventional avocados far outnumbers the total volume output of organic avocados. Moreover, the total volume output of both conventional and organic avocados has grown steadily year after year. This highlights the increasing demand for avocados and the potential for Kenyan producers to tap into this growing market.

The study concludes with a predictive price model using regression analysis. The average price of avocados is used as the predictive goal. The root mean square error (RMSE) came to .12, where the closer to zero it is, the better the model due to fewer errors. The low score showcases how minimal the errors are in the model when comparing predicted vs. actual data. At the same time, Prediction Confidence is 98.29%. This indicates the reliability of the predictive model in making predictions when new cases arrive. This predictive model can be a valuable tool for Kenyan producers in forecasting avocado prices and adjusting their production strategies accordingly.

The paper "Predicting Price of Daily Commodities using Machine Learning" (doc\_id: f7946e7f-9cda-4477-9230-0650f4358c6e) discusses the application of machine learning techniques in predicting the price of daily commodities. The paper highlights the historical dominance of statistical methods such as Moving Average (MA) and Autoregression (AR) in the field of data analysis. However, with the advent of data mining techniques, machine learning has gained popularity in time-dependent analysis. The paper emphasizes the effectiveness of non-parametric models in addressing the complex dynamics of commodity prices.

The paper presents a detailed discussion on the application of machine learning in various domains including agriculture and economics. The authors highlight the use of machine learning in predicting inflation movements, forecasting distorted demand signals in supply chains, and predicting the price of daily commodities. The paper also discusses the use of different machine learning algorithms such as Long Short Term Memory (LSTM), Support Vector Machine for Regression (SVR), and Multilayer Perceptron (MLP) in achieving accurate predictions.

The paper also presents a case study on the prediction of avocado prices in the United States. The authors use historical sales records and weather data to estimate the sales of avocados. The study employs Linear Regression, Multilayer Perceptron, Support Vector Machine for Regression, and Multivariate Regression Prediction Model, with the latter two achieving the best results. This case study illustrates the potential of machine learning in predicting the demand and prices of commodities like avocados.

The paper concludes with a discussion on the future of machine learning in the field of commodity price prediction. The authors suggest that the integration of machine learning with traditional statistical methods could lead to more accurate and reliable predictions. This integration could potentially revolutionize the field of commodity price prediction, providing valuable insights for producers, consumers, and policymakers.

The paper "Estimating Avocado Sales Using Machine Learning Algorithms and Weather Data" (doc\_id: 6219462a-3a25-49bc-9883-8b5aaa4ff7bd) presents an innovative approach to predicting avocado sales using machine learning algorithms and weather data. The authors highlight the importance of data availability and quality in conducting such studies. They discuss the heterogeneity of the data used in the study, which was addressed in the pre-processing phase, and suggest that this could be further analyzed in future research.

The paper discusses the use of four algorithms for generating models, namely Support Vector Machine for Regression and the Multivariate Regression Prediction Model, which showed the best results with a correlation coefficient of 0.995 and 0.996, respectively. The authors suggest that other algorithms or approaches could be further analyzed in future works, such as linear and nonlinear machine learning algorithms, metaheuristic algorithms, genetic algorithms, and deep learning.

The authors also discuss the potential benefits of their approach. The generated models allow for estimating the profits in dollars and the number of avocados that will be sold in the markets of the United States, based on the climatic conditions that could occur. This information can be the basis for producers to decide which market they will sell their product on. Furthermore, supermarket chains or vendors could estimate future sales for administrative or accounting purposes.

The paper concludes with a discussion on future work, proposing the use of additional weather information to improve the accuracy of the system. They also propose to improve the system using other important parameters, such as the imported and produced avocados number, and to train it to estimate not only sales but also other variables, such as price and best variety for markets in the United States and in other countries.

However, the application of machine learning in predicting avocado demand and prices is still in its nascent stages, particularly in the context of Kenyan producers. Despite the potential benefits, there are several challenges associated with the implementation of machine learning models. These include the need for large datasets, the complexity of the models, and the requirement for specialized skills and resources. Furthermore, the effectiveness of these models can be influenced by the quality and relevance of the input data. Therefore, it is crucial to ensure that the data used for training and testing the models accurately reflect the dynamics of the avocado market.

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