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FORECASTING LEAFY VEGETABLE PRODUCTION IN BANGLADESH: UNRAVELLING THE NEXUS AMONG AGRO-METEOROLOGICAL FACTORS

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ABSTRACT

Leafy vegetables in the food basket provide vital nutrients required for human health, but Bangladesh faces challenges of sustainable production potential due to the vulnerability of various agrometeorological factors. This study has addressed a holistic approach to forecasting leafy vegetable production through the nexus of agricultural responses and climatic factors. The secondary yearly data of seasonal leafy vegetable production and area wise daily key climatic predictors such as rainfall, humidity, sunshine, and temperature for the period 2000-2001 to 2022-2023 have been collected from Bangladesh Bureau of Statistics (BBS) and Bangladesh Meteorological Division (BMD), respectively. Scenario analysis and stepwise dynamic regression model was applied to diagnose the pattern and also forecast winter and summer leafy vegetable production for the years 2023-2024 to 2030-2031 addressing meteorological predictors. Results show that winter production is significantly influenced by the previous year's output (lag-1), sunshine hour, and maximum temperature. In contrast, summer leafy vegetable production is influenced solely by previous year production. Using growth projection of sunshine hours and maximum temperature of Bangladesh Meteorological Department (BMD) in the fitted dynamic regression model, winter leafy vegetable production is forecasted to rise from 167,558 tons in 2022-2023 to 211,929 tons by 2030-2031. Summer production is expected to increase from 176,234 tons in 2022-2023 to 285,085 tons by 2030-2031. These findings provide critical insights for policymakers aiming to enhance food security and stabilize leafy vegetable markets amidst climate change for achieving sustainable development goals (SDG) 12.

Keywords: Climate Change, Dynamic Regression, Leafy Vegetable, Scenario Analysis

1. INTRODUCTION

Leafy vegetables are referred to as the edible leaves consumed as vegetables. These vegetables are a vital component of the human diet, providing essential nutrients that play a crucial role in maintaining public health Khatun et al. (2013). In Bangladesh, commonly cultivated leafy vegetables include Kachu Shak (Taro stem), Indian Spinach (Puishak), Danta Shak (Stem amaranth), Patshak (Jute spinach), Kalmilshak (Water amaranth), Spinach (Palong Shak), Red Amaranth (Lal Shak) and Laushak (Pumpkin leaves). Additionally, they are an excellent source of essential nutrients such as iron, calcium, and various phytochemicals, including vitamin C, carotenoids, lutein, folate, magnesium, and vitamin K. These micronutrients are essential for supporting healthy bodily functions, and leafy vegetables provide a primary source of dietary inorganic nitrates, which contribute to nitric oxide production, and support cardiovascular health Ara (2015). In Bangladesh, where agriculture plays a central role in food security and livelihoods, leafy vegetables have become a staple due to their nutritional value, affordability, and availability. The growing population (around 170 million) has created an increasing demand for food, including leafy vegetables BBS (2022). However, despite their abundance, the current consumption of vegetables in Bangladesh remains well below the recommended levels. According to the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), individuals should consume at least 400 grams of fruits and vegetables daily, specifically 200 to 250 grams of vegetables WHO (2023). In Bangladesh, the average per capita fruits and vegetable intake was 297.3 grams in 2022, consisting of 95.4 grams of fruits and 201.9 grams of vegetables, which included 54.44 grams of leafy vegetables (26.96% of total vegetable intake) (HIES, 2022; Zaman, 2024). As fruits can be too pricey for many, which makes leafy vegetables a more budget-friendly and available source of essential nutrients. However, this is still below the standard level of vegetable intake, which is 250 grams per day. To cross the standard limit of vegetable intake (250 grams per day) considering the proportion of the year 2022 as constant, a person needs to intake at least 64.71 grams of leafy vegetables. The agricultural sector, especially leafy vegetable production in Bangladesh faces numerous challenges, including limited land availability, rapid climatic change and extreme weather events, such as temperature, sunshine hours, humidity, and rainfall. These factors play a crucial role in determining the production of leafy vegetables. Given the country's dependence on agriculture for food security, it is essential to understand how these agro-meteorological factors affect both production in the summer and winter seasons. Despite the recognized importance of leafy vegetables in the diet and their role in public health, in-depth research on their seasonal production trends and the influence of agro-meteorological factors remains limited. Previously, Das, et al. (2023) showed that spinach production in Bangladesh is influenced by factors such as area under cultivation, sales price, and meteorological conditions, with price being the strongest predictor. But still, there is no holistic research on leafy vegetables that forecast seasonal leafy vegetable production considering seasonal agrometeorological factors as dynamic predictors. Forecasting seasonal production, considering these climatic and weather variables, can provide valuable insights for developing sustainable agricultural practices and mitigating the risks posed by climatic factors. This study seeks to address this gap by analyzing the nexus between agrometeorological factors such as maximum temperature, sunshine hours, and rainfall and leafy vegetable production in Bangladesh. Specifically, the aim of this study is to analyze consumption patterns of leafy vegetables in Bangladesh; forecast and measure the target of production for both the winter (December-February) and summer (March-May) seasons considering meteorological variables as predictors; and provide recommendations to ensure sustainable leafy vegetable production and food security in light of climate change. This research is particularly significant given the increasing reliance on leafy vegetables as an affordable source of essential nutrients. The findings are expected to inform policymakers and agricultural stakeholders about the strategies required to boost production and adapt to the changing environmental conditions, ultimately contributing to long-term food security in Bangladesh.

2. MATERIALS AND METHODS

2.1. SOURCES OF DATA

Data for this study were gathered from multiple sources to provide a comprehensive analysis of leafy vegetable production and its relationship with climatic factors in Bangladesh. Information on the consumption of leafy vegetables was collected from the Household Income and Expenditure Survey (HIES) for the period 2000 to 2020. This dataset provided insights into the dietary patterns of the population and the role of leafy vegetables in the overall diet. For production data, records of both winter (December-February) and summer (March-May) leafy vegetables were sourced from the Bangladesh Bureau of Statistics (BBS). The data covered the agricultural years from 2000-2001 to 2022-2023, enabling a detailed analysis of trends in production across different seasons. Climatic data, essential for analyzing the impact of weather conditions on leafy vegetable production, were obtained from the Bangladesh Meteorological Department (BMD). This dataset included key variables such as rainfall, humidity, sunshine, and temperature. The data of these agro-meteorological factors were collected from eight weather stations from each of Bangladesh's administrative divisions. The data were then averaged across all divisions to create a national-level dataset for both the summer and winter seasons, covering the same timeframe as the production data. This national-level analysis provides a robust foundation for understanding the influence of climatic variability on leafy vegetable production over time.

2.2. STATISTICAL ANALYSIS

Exploratory analysis and polynomial regression were applied to diagnosis the pattern of future food intake of leafy vegetables. A dynamic regression model was selected for analyzing and forecasting leafy vegetable production in Bangladesh. This model was chosen due to its ability to account for time-dependent relationships between past and current production levels. Specifically, the model incorporated lagged production as a predictor, allowing us to capture the influence of the previous year's output on the current year's production. This is particularly relevant for agricultural production, where previous yields and agricultural practices often affect future outcomes. In addition to lagged production, key climatic variables were included in the model to assess their impact on both winter and summer leafy vegetable production. The model selection process was guided by the goal of minimizing forecast errors and improving predictive accuracy. Various model configurations were tested, and the inclusion of statistically significant variables was prioritized to ensure the robustness of the model. By considering both agrometeorological factors and historical production data, the stepwise dynamic regression model provides a comprehensive tool for forecasting future leafy vegetable production in response to changing climatic conditions.

3. RESULTS AND DISCUSSION

3.1. PER-CAPITA FOOD INTAKE PATTERNS OF LEAFY VEGETABLES IN BANGLADESH

From the Household Income and Expenditure Survey (HIES) from 2005 to 2022, the intake of leafy vegetables did not exhibit a straightforward linear pattern. Instead, the data showed an initial decrease from 2005 to 2010, followed by an upward trend from 2010 to 2022. A quadratic model was applied to capture this Ushaped non-linear trend, which is more appropriate for understanding the data's historical changes and predicting future values. The fitted model, with an adjusted R-squared value of 0.998, accurately represents the relationship and includes a polynomial growth curve reflecting per capita daily vegetable intake (in grams) for the years 2005, 2010, 2016, and 2022.

Figure 1

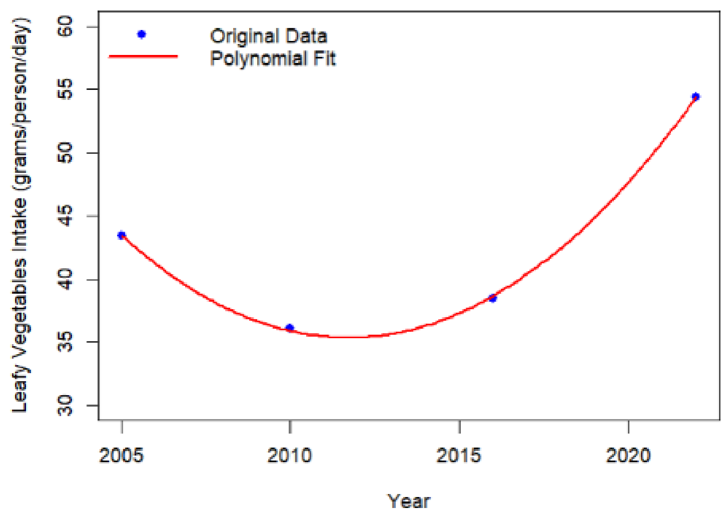

Figure 1 Fitting Quadratic Model

The projected per capita daily intake of leafy vegetables (in grams) from 2022 to 2030 will increase 54.44 to 95.44 grams. The projections indicate a continued increase in consumption, suggesting that dietary intake of leafy vegetables will rise steadily throughout the decade.

3.2. IDENTIFICATION OF SIGNIFICANT AGROMETEOROLOGICAL FACTORS FOR SEASONAL PRODUCTION

The identification of significant agrometeorological factors affecting seasonal production highlights key relationships between weather variables and leafy vegetable production. In summer, production shows a positive correlation with maximum (r = 0.35) and minimum temperature (r = 0.29), while it is negatively affected by rainfall (r = -0.25), sunshine (r = -0.35), and humidity (r = -0.24). But, there is no any significant correlation of summer production with climatic variables. Conversely, in winter, production is positively correlated with rainfall (r = 0.41*) and minimum temperature (r = 0.28), but negatively impacted by sunshine (r = -0.74***), indicating that excessive sunlight can harm yield during colder months. In this case, winter production is significantly correlated at Sunshine hours and Rainfall. These findings emphasize the seasonal variability in how meteorological factors influence crop production.

Table 1

Table 1 Association Studies Between Production with Climatic Factors

		Production	Rainfall	Sunshine Hours	Humidity	Maximum Temperature	Minimum Temperature
Production	Summer	1					
	Winter	1					
Rainfall	Summer	-0.25	1				
	Winter	0.41*	1				
Sunshine	Summer	-0.35	-0.48**	1			
	Winter	-0.74***	-0.33	1			
Humidity	Summer	-0.24	0.75***	-0.4*	1		
	Winter	0.22	0.06	-0.58***	1		
Maximum Temperature	Summer	0.35	-0.66***	0.21	-0.79***	1	
	Winter	0.07*	-0.05	0.27	-0.27	1	
Minimum Temperature	Summer	0.29	-0.23	-0.15	-0.18	0.7***	1
	Winter	0.28	0.12	-0.2	0.36*	0.65***	1

We initially, fit the multiple regression model of each summer and winter with all climatic variables. In these models, almost most variables/predictors. In this test we have observed that, initial (full) model) have autocorrelation problem. There is need to regress production with lag production with climatic variables. Using a stepwise dynamic regression model highlights key agrometeorological factors influencing leafy vegetable production in Bangladesh. For winter production, significant variables include previous year's output (lag-1), maximum temperature, and sunshine hours. Interestingly, the model indicates a negative relationship between sunshine hours and leafy vegetable production, meaning that as sunshine hours decrease, production tends to increase. This counterintuitive result can be understood in the context of changing seasonal patterns and the specific growing conditions of leafy vegetables. The sunshine hours in Bangladesh have been decreasing (a trend supported by data from the Bangladesh Meteorological Department), but production of leafy vegetables is increasing over time. While sunshine is generally beneficial for plant growth, excessive sunlight during the winter months may lead to stress on certain crops, especially leafy vegetables that thrive under cooler, more moderate conditions. On the other hand, maximum temperature shows a positive effect on production, suggesting that slightly warmer winter temperatures within an optimal range may enhance growth by preventing cold stress. In contrast, for the summer production, the model identifies lagged production as the sole significant factor, indicating that the previous year's output is the primary determinant of summer leafy vegetable yields. This suggests that summer production may be more resilient to climatic variations, relying more on agricultural practices and previous yields than on direct meteorological factors such as sunshine and temperature. The summary of the model, presented in Table 1, highlights the coefficients, standard errors (SE), and Variance Inflation Factor (VIF) for each significant variable.

Table 2

Table 2 Model Summary of Dynamic Regression Model

Response: Leafy vegetables production (m.ton)	**Summer**		**Winter**		
	Coef.	***SE (Coef.)***	***Coef.***	***SE (Coef.)***	**VIF**
Intercept	4109.51	5009.12	-122350.9	48950.6	
Lag (leafy vegetable production)	1.04***	0.06	0.88	0.04	1.94
Sunshine Hours			-6995.86	2106.26	2.19
Maximum Temperature			7000.03	2002.96	1.21
R^2	0.94		0.98		
AIC	479.795		441.83		
DW	2.065		1.94		

3.3. FORECASTING THE LEAFY VEGETABLE PRODUCTION

To forecast leafy vegetable production, we first projected key climatic factors, including sunshine hours and maximum temperature, using data from the "Changing Climate of Bangladesh" report by the Bangladesh Meteorological Department (BMD). These forecasts were integrated into the dynamic regression model to estimate future production for both the winter and summer seasons.

Figure 2

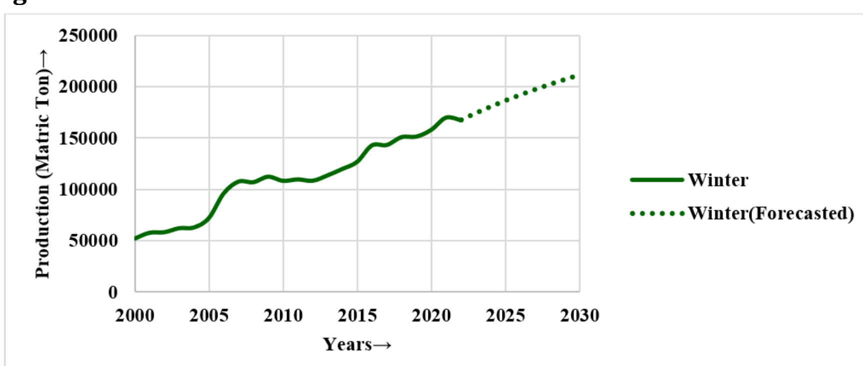

Figure 2 Forecast of Winter Production

For winter production, the forecasts indicate that as average maximum temperatures is almost stable and sunshine hours decline, production is expected to rise. This suggests that warmer winters, combined with shorter sunshine hours, may create more favorable conditions for leafy vegetables, which tend to thrive in cooler, more moderate environments. The forecast for winter leafy vegetable production shows a steady upward trend over the period from 2023-2024 to 2030-2031 Figure 1. In contrast, the forecast for summer leafy vegetable production relies heavily on the lagged effect of the previous year's output, as climatic factors were not found to significantly influence summer yields Figure 2. Despite this, summer production is also projected to increase, reflecting improvements in agricultural practices and consistent growth in production capacity.

Figure 3

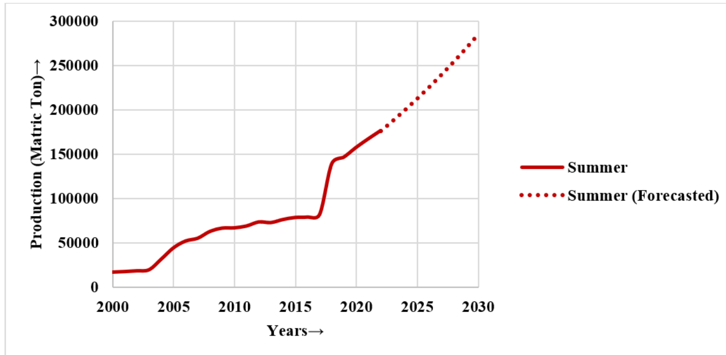

Figure 3 Forecast of Summer Production

These forecasts provide crucial insights into the future availability of leafy vegetables in Bangladesh. Policymakers can use these projections to plan for potential shifts in supply and ensure that the growing demand for leafy vegetables is met, particularly in the context of climate change and population growth.

4. CONCLUSION

This study highlights the key agrometeorological factors influencing leafy vegetable production in Bangladesh, revealing that winter production is significantly affected by declining sunshine hours and rising maximum temperatures. The forecasts indicate an overall increase in production for both winter and summer seasons from 2023-2024 to 2030-2031, driven primarily by previous year's output in summer. These findings underscore the need for adaptive agricultural strategies to enhance resilience against climate change. Policymakers should focus on sustainable farming practices and improving supply chains to ensure food security as demand for leafy vegetables continues to rise. Overall, this research provides essential insights for managing the challenges posed by changing climatic conditions in Bangladesh's agricultural sector.

CONFLICT OF INTERESTS

None.

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