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Original scientific paper

MODELING FACTORS INFLUENCING BARLEY YIELD IN ETHIOPIA: AUGMENTED COBB-DOUGLAS PRODUCTION FUNCTION APPROACH

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ABSTRACT

Barley production in Ethiopia is constrained by climatic and non-climatic factors. The objective of this study was to examine the influence of climate change and non-climatic inputs on barley yield in Ethiopia. The study employed an augmented Cobb-Douglas production function approach to model factors influencing barley yield in the country. The results revealed that short/belg-season rainfall and temperature variables showed positive relationship with barley yield, having minimal positive impact on yield of barley. The positive elasticity of short/belg-season rainfall is justified by the fact that short duration barley crops are grown in the highlands of Bale, North Central Shewa, and Wollo zones contributing less than 10% of total grain production.Conversely, long/main-season rainfall showed negative impact on yield of barley, which due to extreme rain events such as high rainfall above optimum requirement of the crop as well as scarcity of rainfall in some pocket areas. The result infers that cultivation of barley in Ethiopia moderately depends on rainfall. Among the non-climatic variables, irrigated land area under barley cultivation, fertilizer quantity used, and improved barley seed used had positive impact on barley yield. Fertilizer and improved seed inputs had positive and significant impact on barley yield. The result implies that barley yield is highly responsive to use of fertilizer and improved barley seed inputs and moderately responsive to irrigation input. Conversely, land area cultivated under barley crop had negative impact on barley yield, although not significant.

Key words: Climate Change, Non-Climatic Factors, Barley Yield.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most important food crops in the world in general and in Ethiopia in particular for a long period of time. It is the fourth most important cereal crop in the world in terms of production (Yawson, *et al*, 2020), following wheat, rice and maize (Tuttolomondo, *et al.* 2009). It is also a major cereal crop in Ethiopia accounting for 9% (0.95 million hectares) of total area under cereal crops and 9% (2.378 million tons) of total cereal production (CSA, 2020). Barley is one of the staple cereal crops in Ethiopia after teff, maize, wheat and sorghum (CSA, 2018). In Ethiopia, barley is mainly consumed as food sources and for preparing popular traditional drink (*Tella*) (Araya, *et al.* 2021).

Ethiopia is considered as a center of barley diversity (Lakew, *et al.*, 1997) with a high level of morphological variation between landraces that resulted from adaptation to diverse climatic conditions and soil types. Long- term geographic isolation likely contributed to this diversity (Mekonnon, *et al.*, 2014) because barley is a founder crop of Old World agriculture and may have been cultivated in Ethiopia for the last 5.000 years (Bekele, *et al.*, 2005). In present time, farmers cultivate barley in Ethiopia from 1.400 to over 4.000 meters above sea level (m.a.s.l) under highly variable climatic and edaphic conditions (Asfaw, 2000).

Barley is cultivated in all regions of Ethiopia. The most important barley producing regions are Shewa, Arsi, Bale, Gojam, Gonder, Welo, and Tigray. Belg barley is produced mainly in Wollo, Shewa and Bale. The estimated production of barley between 1981 and 2020 was 1.08 and 2.38 million tons respectively, which showed an increase of about 220% over the years.

However, barley production in Ethiopia is constrained by several factors such as climate change (high inter-annual rainfall variability and increasing temperature), unpredictable drought stress, low yield potential of currently grown cultivars, and infestation of diseases, insect pests and weeds (Wosene, *et al,* 2015). Among these factors, change in climate significantly affects crop yields and production. The Intergovernmental Panel on Climate Change (IPCC) confirmed that human activities are changing the climate system and will remain to do so (IPCC, 2014). In the previous century, the impacts of changes in surface temperatures and precipitation on physical and biological systems are progressively being observed. Many of the African countries, including Ethiopia are highly vulnerable to the elaborated impacts of climate change as they have poor access to mitigation and adaptive resources. Some researchers have measured the impacts these factors on barley yield over different regions and locations and reported that climatic parameters have adverse impact on barley yield. Bekele, et al, (2019) in their modeling of climate change and its impact on food barley explored an overall increasing trend in temperature and significant variation of seasonal rainfall from the historical period of time which adversely affected barley yield. Araya, *et al.* (2021) modeled crop management and climate change sensitivity on food barley in northern Ethiopia and reported that a rise in temperature alone by 2, 4, 6 and 8 ^{o}C from the baseline significantly reduced barley yield. Ginbo (2022) in his heterogeneous impacts of climate change on crop yields across altitudes in Ethiopia discovered that climate change reduces barley, maize, and wheat yield by 22.7%, 48%, and 10%, respectively, at high altitudes. Equally, Tuttolomondo, *et al.* (2008) simulated the effect of climate change in barley yield in Italy and reported that yield variability increases slightly with a rise in variability of both temperature and rainfall levels. These findings inform that changes in climatic parameters, such as sea level rise, rising atmospheric temperatures and altering rainfall patterns will pose crop yield reduction including barley.

In view of the sensitiveness of climate change to barley yield, the attempts made to quantify the likely impact of climatic variables on barley yield are limited. Few studies (Bekele, *et al,* 2019; Araya, *et al.* 2021; & Ginbo, 2022) examined the impact of climate change on yield of barley. However, these studies were limited to few pocket areas and locations and did not cover the main barley growing belts. There is scarcity of such empirical studies with national scope on the impact of climate change on barley production in Ethiopia. Hence, it would be realistic and meaningful to study the impact of changes in climate on the yield of barley aggregately at national level covering the main barley growing belts. The main objective of this study was to examine the influence of climate change and non-climatic inputs on barley yield and provide information that could be used for future mitigation and adaptation responses.

MATERIAL AND METHODS

Data Type and Source

The current study used time series secondary data for the selected variables covering the period from 1981 to 2020. The study used one independent variable, viz. yield of sorghum expressed in kgs/hectare; and explanatory variables, viz. crop growing period seasonal rainfalls expressed in millimeters (mm), crop growing period mean minimum and maximum temperatures expressed in (ºC), land area cultivated under sorghum expressed in million hectares, fertilizer quantity used on sorghum cultivation, and improved sorghum seed). Data on production and yield of sorghum crop as well as land area cultivated under sorghum were taken from Agricultural Sample Survey Reports of Ethiopian CSA which covered the period from 1981 to 2020. Secondary data on weather variables (minimum and maximum temperatures and crop growing period rainfalls, i.e. short-season/*belg* and long-season/*meher* rainfalls) were purchased from the Ethiopian National Meteorological Agency (NMA). After purchasing the data, representative weather stations from barley crop growing belts were selected (12 stations) and data on crop growing period average precipitation and atmospheric temperatures was calculated from data recorded in NMA database. Equally, nationally aggregated average (pooled) data of crop growing period climate data were by taking average of weather stations selected for the study over the period 1981 to 2020.

Empirical Model Specification

Researchers like Gupta, *et al*, (2012) and Shumatie, *et al.* (2017) have adopted Cobb-Douglas production function for investigating impact of climatic variability on cereal crops productivity utilizing panel and time series data. Thus, this study has considered barley yield to evaluate impact of climate change and employed augmented Cobb-Douglas production functional model to examine climatic and non-climatic factors influencing the yield of barley. The model assumes that agricultural production is a function of many variables such as cultivated area, fertilizers, seeds, oxen power, labors, working capital, rainfall and temperature. In line with production theory, it is more likely that the relationship between climate and non-climate variables and crop yield takes non-linear form (Chen, *et al*, 2004 and Just and Pope, 1979). According to Chen, *et al* (2004) and Just and Pope (1979), the model provides more significant results compared to linear functional form. The model assumes that crop yield and agricultural production is a function of many endogenous and exogenous variables like cultivated area, irrigated area, fertilizers, improved seed, etc. The Cobb-Douglas production function, in its stochastic form (Gujarati, 2004), can be expressed as:

$$Y_t = AX_1^{\beta 1} X_2^{\beta 2} \ldots X_n^{\beta n} e^{\varepsilon} \quad (1)$$

where, Y_t is a dependent variable (yield of barley), $X_{s'}$ are vectors of independent variables incorporated in the regression analysis and $\beta_{s'}$ are parameters to be estimated. A is constant term, e is base of natural logarithm and ε is the error term with zero mean and constant variance. This non-linear form of Cobb Douglas production function can be estimated through ordinary least squares (OLS) by taking natural log on both sides of equation (1), which becomes log-linear form. Estimates of this form of production function give direct elasticities of variables. The log-linear form of Cobb Douglas production function in this regard is expressed as:

$$\ln Y_t = \beta + \beta i \sum_{i=1}^{n} \ln X_i + \varepsilon i \qquad (2)$$

where lnY_t shows barley yield (quintal per hectare) at time t, X_i is vector of farm inputs including cropped land area, fertilizer, improved seed, irrigated area, etc. However, time series data were unavailable for some of the farm inputs like farm machinery, oxen power, and laborers. In its functional form, the Cobb-Douglas production function under equation (2) is specified as:

$$\ln Y_t = \alpha_0 + \beta_1 \ln BLa_t + \beta_2 \ln Fert_t + \beta_3 \ln BImS_t + \beta_4 \ln IrrgAr_{it} + \varepsilon_t \qquad (3)$$

where, $\ln Y_t$ is the natural log of yield of barley (quintal per hectare), $\ln BLa_t$ is natural log of cropped land area under barley crop, $\ln Fert_t$ is natural log of fertilizer used under barley crop, $\ln BImS_t$ is natural log of barley improved seed used, and $\ln IrrgAr_t$ is natural log of irrigated land area under baley crop at time t. ε is the usual error term independently and identically distributed.

The Cobb-Douglas production model further assumes that climatic factors are influential input factors for yield of crops. Climatic variables considered in this study were rainfall and temperature, where mean minimum and maximum temperatures for crop growing period (i.e. February to September), and mean rainfall for *Short*- (belg) and *long*- (main) *seasons* were considered. After incorporating climatic variables, equation (3) in its log-linear form has been specified as follows:

$$\ln Y_t = \alpha_0 + \beta_1 \ln BLa_t + \beta_2 \ln Fert_t + \beta_3 \ln BImS_t + \beta_4 \ln IrrgAr_t + \beta_5 \ln SSRF_t + \beta_6 \ln LSRF_t + \beta_7 \ln MinTemp_t + \beta_8 \ln MaxTemp_t + \varepsilon_t \qquad (4)$$

where: $\ln Y_t$ is the natural log of yield of barley (quintal per hectare), $\ln BLa_t$ is natural log of cropped land area under barley, $\ln SSRF_t$ is natural log of *short/Belg-season* rainfall, $\ln LSRF_t$ is natural log of *long/Meher-season* rainfall, $\ln MinTemp_t$ is natural log of crop growing period mean minimum temperature recorded during cropping seasons, $\ln MaxTemp_t$ is natural log of crop growing period mean maximum temperature recorded during cropping seasons, $\ln Fert_t$ is natural log of fertilizer used under barley, $\ln BImS_t$ is natural log of barley improved seed used, $IrrgAr_t$ is natural log of irrigated area under barley, t = time period from 1981 – 2018, α_0, β_1, β_2, β_3, β_4, β_5, β_6, β_7, and β_8 are unknown parameters to be estimated, and ε_t is the error term. To estimate the Cobb-Douglas production model specified by equation 4, ***MedCal- Version 19.1 software*** **and** ***SPSS 24 Statistical packages*** were used.

Method of Estimation

Barley crop yield model selected for this study has been estimated using ordinary least squares method. The models have been estimated consistently by Ordinary Least Squares (OLS) if the error term (ε_j) is a white noise process or more generally, if the error term has a zero mean, constant variance and uncorrelated with the explanatory variables and its previous realizations.

The models have been estimated using annual time series data for the period between 1981 and 2020. Prior to model estimation, the data series have been subjected to various tests to confirm various properties required for OLS to give results that are efficient and consistent.

Since this study uses time series data, it was necessary that, before estimation of the equations, the series must be tested for satationarity/ *unit root* and existence of serial autocorrelation using appropriate methods and tools. In this study, two widely used methods were chosen: Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) and Phillips-Perron (PP) test (Phillips and Perron, 1988) to check the presence of unit roots in the data series. The ADF test for stationarity in a series y involved estimating the equation:

$$\Delta y_t = \mu + \beta_t + \gamma\, y_{t-i} + \sum_{i=1}^{p} \emptyset_i \Delta y_{t-i} + \varepsilon_t \qquad (5)$$

where μ is the drift (intercept), t is the trend, i is equal the number of lags in Δy_{t-i}, p is the maximum number of lags determined using Akaike Information Criterion (AIC) and Schwartz Criterion (SC) and ε_t is the random error term. The null hypothesis H_0: $\gamma = 0$ (unit root) was tested against the alternative hypothesis H_A: $\gamma < 0$ (no unit root). If the computed test statistic was found greater than the critical value then the null hypothesis was not rejected. If H_0 could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary. If its first difference is then tested and found stationary, the series was concluded to be an I(1) (Green, 2008; Gujarati, 2004; Dickey and Fuller, 1979).

Time series were also subjected to a Phillips –Perron (PP) test which has a higher power. The PP test took the form:

$$\Delta Y_t = \theta_0 + \sum_{i=1}^{m} \delta_i \Delta Y_{t-i} + \varepsilon t \qquad (6)$$

where ΔY_t was the first difference of the dependent variable; i is the number of truncation lags, where *i=1, 2,…, m*; θ and δ are coefficients and ε_t is the error term. The null hypothesis of, H_0: $\delta_i = 0$ (unit root) was tested against the alternative, H_A: $\delta_i < 0$ (no unit root). If the computed test statistic was found greater than the critical value at 5% level of significance, then the null hypothesis could not be rejected. If H_0 could not be rejected, then the time series variable contained a unit root and hence non stationary, otherwise it was stationary.

RESULTS AND DISCUSSION

Results of Unit Root Tests

Unit root tests have been conducted on all time series and multicollinearity tests between variables incorporated in the model. Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests were used to test the presence of unit root in the data series. In the ADF and PP tests for presence of unit root in time series, the null hypothesis for unit root is rejected when the test statistic is greater than the critical value at desired level of significance otherwise the null hypothesis is not rejected.

The ADF and PP unit root test results are presented in Table 1. The estimated outcome of both ADF and PP tests reflected that the following variables are stationary at level or order I(0): lnBaY, lnBaAr, lnBaIrrgAr, LnFert, LnIMSeed, and LnMaxTemp. Conversely, the following variables were found to be integrated of order I(1): LnSSRF, LnLSRF and LnMinTemp. Thus, the variables used in the study are a mixture of I(0) and I(1). In case time series data exhibit a mixture of I(0) and I(1) some researchers and econometricians recommend Cobb-Douglas or ARDL modeling as best approach (Sharma and Singh, 2019 and Dushko, *et al* 2011).

Table 1. Results of the Unit Root Tests

Variable	ADF				PP				Result
	Level		First Difference		Level		First Difference		
	Computed t-Statistic	Critical Value	Computed t-Statistic	Critical Value	Computed t-Statistic	Critical Value	Computed t-Statistic	Critical Value	
LnBaY	-0.2272***	-4.25288	-6.19942	-4.2436	-2.1793***	-4.2119	-25.041	-4.21913	I(0)
lnBaAr	-3.6455***	-4.21187	-8.5007	-4.21913	-3.6395***	-4.21187	-19.2650	-3.19831	I(0)
LnBaIrrgAr	-3.6975***	-4.21187	-6.9341	-3.20032	-3.7260***	-4.21187	-11.7046	-3.19831	I(0)
LnFert	-2.9416***	-4.21187	-7.2393	-4.21913	-2.9228***	-4.21187	-13.18991	-3.19831	I(0)
LnIMSeed	-1.9332***	-4.21187	-4.9361	-4.23497	-1.7293***	-4.21187	-7.30698	-4.21913	I(0)
LnSSRF	-6.41428	-4.21914	3.8001***	-3.2003	-8.47373	-4.21188	-23.27511	-4.21913	I(1)
LnLSRF	-4.91008	-3.52976	4.0254***	-4.24364	-4.88583	-3.19641	-20.97917	-4.21913	I(1)
LnMinTemp	-6.35686	-3.19641	-2.50206*	-2.89000	-6.12426	-3.19641	-13.78382	-3.19831	I(1)
LnMaxTemp	-0.97548*	-3.77000	-6.82005	-3.20245	-31.0864	-3.19641	-122.4843	-3.19831	I(0)

*, ** and *** indicates significance level at 10%, 5% and 1%, respectively

Diagnostic Tests

Before running the Cobb Douglas production function model, the time series data were tested for serial correlation and multicollinearity. The tests exhibited existence of no serial correlation in the regression models since the Durbin Watson statistic was almost close to 2 in most cases. The test indicates that there is no effect of multicollinearity as the values of VIF are less than 10 for barley crop yield model.

Modeling Impact of Climate and Non-Climatic Variables on Barley Yield

After conducting diagnostic tests explained above, the Cobb-Douglas production functional model was estimated. The barley yield model has been estimated employing ordinary least square technique. The estimated coefficients of the Cobb-Douglas functional model was significant as the F-value (11.4996) indicated that the overall regression model was fitted good and followed normal distribution for the present data. The D'Agostino-Pearson test for Normal distribution proposed to accept Normality at (P=0.4995). Furthermore, the adjusted R^2 was 0.683 indicating that 68.3% of the variation in the model has been explained by the variables included in the model, which implies good fitness of the estimated model.

The explanatory variables included in the model are in their logarithmic form in order to provide convenient economic interpretations (elasticities) and to reduce heterogeneity of the variance. In the estimation of Cobb-Douglas production function, crop growing season (F-S) mean rainfall, *short*-season rainfall, *long*-season rainfall, crop growing period mean minimum and maximum temperatures (Feb-Sept) were included. From the non-climatic variables, land area harvested and irrigated area under barley cropping system, quantity of fertilizer and improved seed used for barley production were incorporated in the barley yield model.

The elasticity estimates of variables included in the model adopted for barley yield analysis are presented in Table 2. The estimated elasticity coefficients show that climatic variables that were included in the model, except *long/main-season* rainfall, showed positive relationship with barley yield, but statistically insignificant. The result implies that *short/belg*-season rainfall and minimum and maximum temperatures have minimal positive impact on yield of barley. The positive elasticity of *short-season/belg* rainfall is justified by the fact that short duration barley crops are grown in the mid-highlands of Bale, North Central Shewa, and North and South Wollo zones from February to May season. According MoA (2001) report, *short/belg-season* contribute less than 10% of total grain production, crucially important for seed-bed preparation for short and *long-cycle meher* crops, and planting *long-cycle* cereal crops (maize, sorghum, millet). Conversely, *long/main-season* rainfall showed negative impact on yield of barley, although the result is insignificant. The negative impact registered on yield of barley during *main/meher-season* can be due to extreme rain events such as high rainfall above optimum requirement of the crop and scarcity of rainfall in some pocket areas. High rainfall above optimum requirement can cause flooding, logging of crops and landslides which also affects yield of barley. Scarcity of rainfall during critical crop growth periods can lead to wilting of the stalk of the crop; inhibit proper vegetative growth of the crop; and shrinks grain filling. This infers that cultivation of barley in Ethiopia moderately depends on rainfall. The finding of this study is analogous to that of Kim and Pang (2009). In their study on the impact of climate change on rice yield in Korea, they reported that temperature is positively related to average rice yield. The elasticity for temperature is calculated as 0.82-0.89; thus a 1% rise in temperature increases the average rice yield by 0.8 – 0.9%. Precipitation, on the other hand, has negative impact on the average rice yield. According to them, the elasticity for precipitation is estimated as -0.14 ~ -0.05, which are relatively small. The study results of Singh and Sharma (2018) also support the current study. Singh and Sharma (2018) in their study of measuring the productivity of food-grain crops in different climate change scenarios in India found that actual rainfall in Rabi season has negatively associated with barley yield while average minimum and maximum temperatures had positive impact on barley yield, which implies that average minimum and maximum temperatures are beneficial for yield of barley during Rabi season. Conversely, they reported that yield of barley is negatively and adversely affected due to increased actual rainfall during crop growth period.

Similarly, elasticity coefficients for non-climatic variables included in the model were estimated. Accordingly, irrigated land area under barley cultivation, fertilizer quantity used, and improved barley seed used over the observation period showed positive impact on barley yield while land area cultivated under barley crop had negative impact on barley yield, although not significant. Fertilizer and improved seed inputs had positive and significant (at 1% and 5% level) impact on barley yield. The result indicated that a 1% increase in use of fertilizer and seed per unit area will increase barley yield by 0.41% and 0.06% respectively. The result implies that barley yield is highly responsive to use of fertilizer and improved seed inputs. Estimates of this study are similar to those of Kumar and Sharma (2013) and Singh and Sharma (2018). Kumar and Sharma (2013) in their study on the impact of climate change variation on agricultural productivity in India reported that irrigated area and total fertilizer consumption positively affect barley yield, fertilizer consumed being significant at 1% level. The result indicates that a 1% increase in fertilizer use increases barley yield by 0.12%. Equally, Singh and Sharma (2018) in their study on productivity of food grain in India during Rabi season found that cropped area and irrigated area under barley crop had positive impact on barley yield, the elasticity coefficients being 0.7356 and 0.0569. These coefficients, however, are statistically insignificant.

Table 2. Estimates of Cobb-Douglas Production Function from barley yield model

Independent variables	Coefficient	Std. Error	t-stat	P-value	VIF
(Constant)	2.6724				
lnBaArea	-0.01023	0.2162	-0.0473	0.9626	1.549
lnBaIrrigarea	0.008872	0.05726	0.155	0.8779	1.282
lnFertQ	0.4076***	0.06314	6.455	<0.0001	1.526
lnImpSeed	0.0757**	0.02818	2.687	0.0115	1.646
lnSSRF	0.08750	0.1579	0.554	0.5835	1.399
lnLSRF	-0.06383	0.2709	-0.236	0.8153	1.533
lnMinTemp	0.8118	0.6591	1.232	0.2273	2.056
lnMaxTemp	0.03473	0.3529	0.0984	0.9222	1.890
Sample size					40
Coefficient of determination R^2					0.7480
R^2-adjusted					0.6829
Multiple correlation coefficient					0.8648
Residual standard deviation					0.1526
F-Statistic					11.4996
D'Agostino-Pearson test for Normal distribution					accept Normality (P=0.4995)

** & *** indicates significance level at 5% and 1% respectively.

CONCLUSION

Among the climate variables included in the barley yield model, *short/belg-season* rainfall and temperature variables showed positive relationship with barley yield, but statistically insignificant. The result implies that *short/belg-season* rainfall and minimum and maximum temperatures have minimal positive impact on yield of barley. The positive elasticity of *short-season/belg* rainfall is justified by the fact that short duration barley crops are grown in the mid-highlands of Bale, North Central Shewa, and North and South Wollo zones from February to May season. The *short/belg-season* which contribute less than 10% of total grain production is crucially important for seed-bed preparation for *short* and *long-cycle meher* crops, and planting *long-cycle* cereal crops (maize, sorghum, millet) (MoA, 2001). Conversely, *long/main-season* rainfall showed negative impact on yield of barley, although insignificant. The negative impact registered on yield of barley during *main/meher-season* can be due to extreme rain events such as high rainfall above optimum requirement of the crop and scarcity of rainfall in some pocket areas. High rainfall above optimum requirement can cause flooding, logging of crops and landslides which also affects barley yield. Scarcity of rainfall during critical crop growth periods can lead to wilting of the stalk of the crop; inhibit proper vegetative growth; and shrinks grain filling. This infers that cultivation of barley in Ethiopia moderately depends on rainfall.

Among the non-climatic variables included in the model, the elasticity coefficients of irrigated land area under barley cultivation, fertilizer quantity used, and improved barley seed used over the observation period had positive impact on barley yield. Fertilizer and improved seed inputs had positive and significant (at 1% and 5% level) impact on barley yield. The result implies that barley yield is highly responsive to use of fertilizer and improved seed inputs and moderately responsive to irrigation input. Conversely, land area cultivated under barley crop had negative impact on barley yield, although not significant.

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Data Availability

The data used for this study can be made available upon request provided there is going to be compliance with the owners' policy concerning sharing.

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Author's Contributions
The author has contributed to the study conception and design. The author (*Abera Gayesa Tirfi*) has also performed all the material preparation, data collection and analysis, and writing up of the manuscript.

Declaration of Competing Interest
The author declares that there have been no competing interests.

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