DETERMINANTS OF MILLET PRODUCTION IN NEPAL

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Abstract. Globally, changing climate is harming agricultural production, particularly in underdeveloped nations where an older population faces nutritional poverty and hunger. Nepal being a developing country faces the same problem. Millet as one of the major cereal crops has huge potential to solve nutrient and hunger-related problems because of its multiple uses and geographical as well as climate-favorable conditions in Nepal. In this context, this study has examined the determinants of millet production by the use of the Dynamic Ordinary Least Square Method, Fully Modified Least Square Method, and Canonical Cointegrating Regression. Based on the data from 1988 to 2019 we found that fertilizer, cultivated area, and rural population have a significant impact on millet production. The mean temperature has a negative and insignificant impact on millet production. It means climate change had no significant impact on millet production during the study period. As impact of climate change in farming sector is recently realized, millet production might be affected by temperature more in the coming years. In the present context of the weakening hunger index, these findings could be helpful for the policy makers for increasing millet production in Nepal and taking necessary measures for climate adaptive actions. The study recommends the protection of millet-cultivated areas and retaining the active working-age population in rural areas.
Keywords: *cultivated area, fertilizer, mean temperature, rural population, ARDL, climate change*

Introduction

In the year 2021, 828 million people worldwide experienced hunger which is 146 million additional individuals than a year ago and 150 million greater than in 2019 (UN Report, 2022). It signifies the growing demand for cereal crops in the coming year. It is estimated that the growth of demand for cereal crops will increase by 50-70% more in 2050 (Ladha et al., 2005). Due to population expansion, the demand for this resource will expand steadily over time (Ikhwani et al., 2022). Such figures are highlighting the need for and importance of the increase in the production area as well as the productivity of cereal crops across the world.

Millet, a major cereal crop is grown mainly in Asia and Africa. More than 25 nations in Asia and Africa are involved in the cultivation of millet. India is the largest country for the production of millet followed by Ethiopia (Gebreyohannes et al., 2021). India dominates millet production both in terms of area (approximately 9 million hectares) and output (8.3 million tons), with an average output of 930 kg/ha (Mwasiti, 2013). Given its high levels of iron, calcium, manganese, and methionine, finger millet has better nutritional value than rice, wheat, and corn. Organic millet protein-rich and mineral content helps people avoid diseases including overweight, diabetes, and cardiac problems (Maximize Market Research, 2022). Finger millet may be properly preserved for a long time, and it is particularly significant when food is scarce (Nath Adhikari, 2018). With such inherent features of millet along with growing dietary consciousness, people have started to decide to move from consuming junk food to well-known, nutrient-dense superfoods like millet and derivatives (Maximize Market Research, 2022). The shift in

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consumer habits, which now has boosted their preference for healthier meals, is one of the main determinants behind the increasing demand for millet worldwide. It is also proven by the fact that the size of the world millet marketplace was estimated to be approximately 10.37 billion in 2021, but from 2022 to 2029, it is predicted that the market will generate close to USD 15.11 billion growing at a rate of 4.82% compound annual growth rate(Maximize Market Research, 2022).

Millet crops are suitable for milling, as well as for cooking and eating, and storage (Ma et al., 2023). They have been used around the world in the form of both foods as well as fodder (Hoshino et al., 2010). They are typically suited to be grown in unfavorable environmental situations, such as low soil fertility and low precipitation. These cereals continue to play a significant role in the regular diet of several individuals in several areas of Africa and Asia due to their short planting season and high return under challenging conditions. The dry and semiarid areas of Africa and Asia are where millet crop is mostly produced for food and feed. Millet crops can be cultivated with just as 400-500 millimeters of rainfall annually, and without the use of fertilizers and other inputs, giving farmers working in tough conditions a choice when other crops perform poorly (Nagarajan et al., 2007). Such facts indicate the possibility of minimizing the problem of food deficit through increased production of millet crops.

After rice, maize, and wheat, millet is the fourth most significant crop in Nepal and the production of millet is an essential component of the farming system in Nepal’s mountainous terrain where agricultural land is scarce and food shortage is an issue (Adhikari, 2012). In Nepal, the estimated edible cereal requirements are 8.854, 10.075, and 11.46 million metric tons in 2030, 2040, and 2050, respectively, predicated on the base year 2019 on the productivity level of 3.10 t/ha with a constant growth rate of output 2.26% per annum and the population 1.3% per annum (Gauchan et al., 2022). Nepal is ranked in 81st hunger suffering among the 121 nations and seems to have a moderate level of hunger with a score of 19.1 where above 19.9 indicates that the country is facing serious hunger and below 9.9 the country is denoted as low hunger (Nepal - Global Hunger Index (GHI), 2022). So, the study of determinants of cereal crops is crucial.

In this scenario, the study has attempted to analyze the determinants of millet production in Nepal. There is a two-fold contribution of this study to the existing literature. First, as per the researcher’s knowledge, it is the first study on millet production in Nepal using time series data. There is a dearth of studies on millet production in the secondary database around the world. Second, it contributes to the academicians and policymakers by providing ideas regarding how millet production is being affected by temperature in the Himalayan and the landlocked country of Nepal.

Review of literature

Millet production is affected by different factors. The study by Sharma (2015) indicates that the performance of the harvesting sequence and soil quality are significantly and favorably impacted by the combined fertilizer use and farmyard manure. Eyshi Rezaei et al. (2014) proved that when crop wastes and mineral fertilizer were applied together, pearl millet production was higher than when only one of those inputs was used. Hayashi et al. (2008) supported prior findings that millet yields are increased by micro-dosing with fertilizer, regardless of when it is applied. Growing demand for Nitrogen (N) fertilizer for the food production of 50% of the world’s population Ladha et al., (2005) further highlights the role of fertilizer in cereal crop production.

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Amidst the growing concern about climate change, several researchers have studied the impact of climate-related factors on millet production. A rise in yearly temperature, growing degree days (GDD), and a decline in rainwater in central Nepal have positively impacted the output of finger millet (Luitel et al., 2019). The study in Ghana by Karim et al. (2022) found that sorghum and millet are climate resilient and do not react to changes in climate-related variables. A case study in the Amhara region of Ethiopia by Bewket (2009) confirmed that the variability of rainfall is an important factor influencing changes in cereal production. Prakash and Lall (2011) found that crop productivity is severely impacted by changes in precipitation patterns, such as intense rain that is concentrated in one month. However, the off-season experiment demonstrates that cowpea and pearl millet could both be grown successfully in conditions of intense heat. Besides that, pearl millet showed itself to be a plant that could thrive in conditions of high heat and scare water Nelson et al., (2018) found that pearl millet is a significant climate-resilient crop appropriate for crop production in semi-arid regions around the world because it has higher ceiling temperatures for grain output compared to other cereals. However, Hussain et al. (2022) confirmed that early rainfalls and high temperatures may coincide with crop maturity, which ultimately led to lower grain yields.

Socioeconomic factors were also found to affect millet production. Gitu et al. (2014) found qualities of the head of the household members, finger millet cultivation area, societal and cultural elements, varieties' technological qualities, and source of agricultural knowledge positively influenced the production of finger millet in Mogotio District of Kenya. The study on Nigeria by Mukhtar et al. (2018) proved that a good and substantial association between socioeconomic factors such as cooperative participation, debt, educational levels, extension contact, family size, and off-farm incomes enhanced pearl millet production.

Millet, as a less water-intensive crop, is being popular in the rural sector Guardian News and& Media Limited, (2022). But urbanization is growing rapidly around the world. Due to the rising influx of individuals moving to urban regions in the quest for more future job prospects, urban places in developing nations have been expanding quickly Argaie et al., (2022) and it is hampering rural farming. Gartaula et al. (2012) found that due to rapid urbanization, people's availability of food and methods of survival are gradually changing from those associated with an agricultural-based economy to those associated with an economy based on other sources of earnings which may endanger not only the agricultural sector's contribution to rural livelihood but also the nation's overall food security. With the increasing urban population, there is a huge requirement for pearl millet flour with a longer life span and a shorter cooking time (Nantanga et al., 2008). According to Rao et al. (2006), money and urbanization have a big impact on how much sorghum and pearl millet are consumed. As millet is mostly grown in rural areas, fast urbanization might hamper production.

Expanding the millet production area has become a challenging task due to growing urbanization. As per the existing scenario, Bonham et al. (2012), Ma et al. (2022), and Lubadde et al. (2016) showed the significant role played by cultivated areas in increasing millet production. However, Gebreyohannes et al. (2021) found a negative relation between cultivated area and millet production. Similarly, according to Saxena et al. (2018), the area designated for millet production has significantly decreased over the past several decades. Government policies that increase the cultivation of key grains like rice and wheat as well as of crops like oilseed, cotton, fruits, and vegetables may be the main cause of this reduction (*Table 1*).

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Table 1. *Previous findings*

Author	Country	Data	Methodology	Factors influencing millet production
(Bonham et al, 2012)	India	200 Farmers of Rajasthan in the 10 largest pearl millet-producing district	Structured Interview and Principal Component Analysis (PCA)	Education (-), land owned (+), Irrigation (+), agricultural Income (+), Cultivated land (+), livestock (-) and Distance from major market (-)
(Mwasiti 2013)	Tanzania	385 respondents including 180 farmers, 85 consumers, 76 traders, and 44 processors	Multiple regression model	Education level of household head (+), Peral Millet price (+), Household food priority (+)
(Oladimeji, 2020)	Nigeria	196 Millet based farmers	Input-oriented Data Envelope Analysis and Tobit Regression model	Farm Size (-), labour (-), Seed (-), Inorganic fertilizer (+), organic manure (+) and Agro chemicals (+)
(Ma et al., 2022)	China	1,000-grain weight (KGW), length (L), breadth (B), and L/B ratio of the dehulled foxtail millet grains	Field experiment, polyphenols content (TPC) was determined, Total flavonoids content (TFC), Polysaccharide content (PC), Yellow pigment content (YPC), and Cooking characteristics were determined	Cultivated Area (+), Longitude (-), Latitude (-), Average Temperature (+), Precipitation (+)
(Gebreyohannes et al., 2021)	Ethiopia	240 farmers	A multi-stage sampling procedure was used, Descriptive statistics, cross-tabulation procedure, Contingency chi-square tests, and cost-benefit analysis were summarized	Land Size (-), Soil fertility (-), Access to fertilizer (-), High quality grain (+), Marketability (+) and Early maturity (+)
(Lubadde et al., 2016)	Uganda	160 households	Descriptive statistical analysis and pattern analysis	Cultivated area (+), Spouse age (+), producers experience (+), Age of household head (-), Amount of seed planted (-) and Market distance (-)
(Mukhtar et al., 2018)	Nigeria	430 Pearl millet farmers	Ordinary Least Square (OLS) multiple regression criterion	Credit (+), Education level (+), Cooperative membership (+), extension contract (+), Household size (+), off-farm income (+), Improved seed (+), Producer age (-) and Household size (-)
(Karim et al., 2022)	Ghana	1970 – 2018	Autoregressive Distributed lag cointegration approach (ARDL)	CO_2 emission (-), temperature (-) and rainfall (-)
(Gyawali, 2021)	Nepal	Past literature	Literature-based review	High yielding varities (-), Marketing (-), Preference towards Cereal (-), Subsidy (+), Improving tourism (+), Increase agro based industries (+), Farmers Motivation (+)
(Bewket, 2009)	Ethiopia	1975-2003	least squares regression technique, Spearman's rho test coefficient of variation, and the Precipitation Concentration Index (PCI)	Rainfall amount (-), Rainfall variability (-), Rainfall trend (-), Chemical fertilizer (+) and Other agricultural inputs (+)

Most of the research findings support the millet crop as an environment-friendly crop. Singh et al. (2017) tested thirty-five scenarios of pearl millet production. Out of them, 31

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scenarios harmed the yield of pearl millet up to 41% (+6°C/20% rainfall). During various phases of pearl millet's production, biochar significantly ($p<0.05$) reduced the plant's carbon dioxide (CO_2) emissions. The largest CO_2 emissions were recorded before pearl millet was harvested. Using time series data from 1960-2015 and the autoregressive distributed lag model Owusu and Asumadu-Sarkodie (2017) found that in the short run, a 1% increase in millet and sorghum output will lower carbon dioxide emission by 0.13% and a 0.11% respectively and millet production and carbon dioxide emissions were casually linked in both directions.

Overview of millet production in Nepal

Nepal is topologically situated in the Mountains, Hills, and Terai region. Finger millet is one of the most widely planted millets in Nepal and a crucial staple crop in the hill and mountain farming systems, particularly in the rainfed and marginal agricultural zones (Ragupathy et al., 2016) . Since paddy and wheat cannot be grown in Nepal's hillside due to poverty, millet is the main meal consumed here. The major types of millet crops produced in different parts of Nepal are shown in *Table 2*.

Table 2. *Region-wise millet production in Nepal*

Millet type	Finger Millet	Foxtail Millet	Proso Millet	Sorghum Millet	Barnyard Millet	Pearl Millet	Little Millet Kodo
Nepali name	Kodo	Kaguno	Chino	Junelo	Sama	Bajra	Kutki sama kodo
Scientific name	*Eleusine coracana* L. Gaertn.	*Setaria italica* L. P. Beauv	*Panicum miliaceum* L.	*Sorghum bicolor* L. Moench	*Echinochloa frumentacea* Link	*Pennisetum typhoides* (Burm.f.) Stapf and C.E. Hubb	*Panicum miliaceum* L. *Paspalum scrobiculatm* L.
Distribution	Khotang, Baglung, Sindhupalchowk, Sindhuli, Kaski, Gorkha, Syangja	Mugu, Kalikot, Hulmla, Jumla, Bajhang, Bahira, Dolpa, Lamjung, Gorkha, Ramechhap, Kavre	Mugu, Dolpa, Humla, Jumla, Kalikot, Bahira, Jajarkot.	Across mid-hills and terai, small area.	Gorkha, Lamjung, far western.	Rarely found in Nuwakot and far western Terai.	Rarely found in the far western region of Gorkha, Lamjung, Tanahun, and Dhading.

Source: Gyawali, 2021

Province-wise millet production in Nepal, 2019

Nepal is divided into seven provinces where province no 2 namely Madhesh Pradesh is also known as the plane land area. Among seven provinces in Nepal, Madhesh Pradesh is the only province that is not connected or touched by hilly areas. So, there is a low amount of millet production. Millet is mostly grown in the hillside of Nepal which lies in Gandaki, Bagmati, and Madhesh. The highest millet-growing province is Gandaki Province. Based on the statistical data of 2020 Gandaki province produced 99,741 metric tons of millet in the fiscal year 2019 followed by Pradesh 1 with 97,181 metric tons,

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69,466 metric tons by Bagmati, 19,673 metric tons by Karnali, 15,632 by Sudurpachim, 10,869 metric tons by Lumbini. Madhesh Pradesh is known as the lowest millet-growing province in Nepal because of its geographical area (Government of Nepal, 2020).

Mostly above 600 meters to 2500 meters of sea level in Nepal we can see millet production because of the temperature suit at that part (*Table 3*). Up to 600 meters, August to September is the climate favorable but above 600 meters to 2000 meters of sea level July to August is the best month for millet cultivation and above 2000 meters June to July is considered the climate favorable month. So, millet producers at that area generally harvest millet at the mentioned month. Millet nutrients in comparison to other crops are mentioned in the appendix.

Table 3. *Cultivation pattern of millet production in Nepal*

Elevation	Model of production	Growing season
Sea level to 600 m	Early ripening millet- Paddy	Beginning from the first week of Shrawan till the second week of Bhadra (Aug-Sep)
	Early ripening Maize -Millet -Wheat	
	Maize- Millet - Oilseed crop	
600 m to 2000 m	Millet/Maize	Aashad to Shrawan (Jul-Aug)
	Wheat/ Oilseed crop	
	Millet/Maize - Fallow	
	Millet- Wheat- Oilseed crop	
2000 m to 2500 m	Soybean + Millet - Barley/ Wheat	Jestha to Aashad (Jun-July)
	Millet - Barley - Pseudo cereals	
	Millet- Potato- Wheat	
	Millet – Buckwheat	

Source: Koirala and Subedi, 2011

Materials and Methods

Data

Time series data are studied for empirical research spanning the years 1988 through 2019. The study's primary variables include total millet production, total cultivated area for the millet production, annual mean temperature, fertilizer used, and total rural population. The data source and measurement units are listed in *Table 4*.

Table 4. *Variable name and Data Source*

Variable	Abbreviations	Unit of Measurement	Source
Millet production	MP	Thousand Metric Tons	(Nepal Rastra Bank, 2022)
Rural population	RP	Individual Total	(The World Bank, 2022)
Mean temperature	MT	Celsius degree centigrade	(The World Bank, 2022)
Cultivated area	CA	Thousand hectares	(Nepal Rastra Bank, 2022)
Fertilizer used	FT	Metric Ton	(Nepal Rastra Bank, 2022)

There is a lack of reliable time series data on seasonal millet production in Nepal. So, the study has used total millet production per year. Accordingly, annual mean temperature

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has been used like that of the study done by Ma et al. (2023), Mwasiti (2013), and Mohamed et al. (2002). Similarly, due to the lack of availability of data on pesticides, total fertilizer has been used.

Model specification

Based on the factors influencing millet production disclosed by Karim et al., (2022), other past studies (see *Table 1*) and reliable time series data sources in Nepal the study has developed the following model.

$$MP = f\ (CA, FT, MT, RP) \qquad \text{(Eq.1)}$$

where,
MP = Millet production
CA = Cultivated area
FT = Fertilizer used
MT = Mean temperature
RP = Rural population

Eq^{n} (1) in linear and log near form is expressed as:

$$MP_t = \alpha_t + \beta_1 CA_t + \beta_2 FT_t + \beta_3 MT_t + \beta_4 RP_t + \varepsilon_t \qquad \text{(Eq.2)}$$

$$lnMT_t = \alpha_t + \beta_1 lnCA_t + \beta_2 lnFT_t + \beta_3 lnMT_t + \beta_4 lnRP_t + \varepsilon_t \qquad \text{(Eq.3)}$$

The long-run relationship between the variables under study as mentioned in the model is tested by the procedure applied by Siddiqui (2018). First of all, the order of integration is looked at each variable’s time series parameters by the use of the Augmented Dicky Fuller Test.

The ARDL can be tested with variables that are stationary at various integration levels and do not need the very same order of integration. Additionally, this strategy can be used with a small amount of data. These two aspects of our time series data allowed us to employ the ARDL approach of the cointegration test (bound test).

After confirming the cointegration through a bound test, i.e., the long-run relationship between the dependent and independent variables of the model, we employed the Dynamic Ordinary Least Square (DOLS) method. The result of the DOLS is further justified by the help of Fully Modified Least Square (FMOLS) and Canonical Cointegrating Regression (CCR) methods of cointegration. CCR is also used to test the robustness of the model tested by the DOLS method. These cointegration tests are performed in past studies of agricultural research Kumar et al., (2021; Bhardwaj et al., (2022); Abbas, 2022; Zhang et al., (2022). All the models and methods were tested using Eviews software.

Result

As shown in *Table 5* average millet production, average fertilizer used and average cultivated area during the study period is 283.8048 thousand metric ton110,273 metric tons of fertilizer was used in the cultivated area of 253.3359 thousand hectares, respectively. During that time average mean temperature is 14.16281 Celsius degree centigrade and 20,718,867 mean rural total population.

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Table 5. *Descriptive statistical analysis (1988-2019)*

	Millet Production (Thousand Metric tons)	Fertilizer (Metric Tons)	Rural Population (Individual Total)	Yearly Mean Temperature (Celsius degree centigrade)	Cultivated Area (Thousand hectares)
Mean	283.8048	110273	20718867	14.16281	253.3359
Median	290.5	65718	21540738	14.175	262.2734
Maximum	320.9525	400541	22843201	14.97	278
Minimum	196	3157	16536205	13.13	196
Std. Dev.	29.23632	118625.2	1910157	0.426556	24.62047
Skewness	-1.376059	1.205763	-0.864865	-0.246718	-1.702713
Kurtosis	4.34706	3.024768	2.416395	3.055061	4.248227
Jarque-Bera	12.51829	7.754758	4.443412	0.328682	17.54
Probability	0.001913	0.020705	0.108424	0.848453	0.000155
Sum	9081.754	3528735	663000000	453.21	8106.75
Sum Sq. Dev.	26497.63	436000000000	113000000000000	5.640447	18791.19
Observations	32	32	32	32	32

Table 6 shows that three variables lnMP, ln RP, and lnMT are stationary at level [I(0)] and the remaining variables are stationary at first difference [I(0)]. This feature allows us the process further for the ARDL F-Bounds Test. The outcome of the F-bound test is shown in *Table 7*.

Table 6. *Unit root test (Augmented Dicky Fuller Test)*

Variables	At level		At first difference	
	Intercept	Trend and Intercept	Intercept	Trend and Intercept
lnMP	-4.19521*** 0.0026	-3.42089* 0.0712	-7.52338*** 0.0000	-7.57605*** 0.0000
lnFT	-1.12736 0.6921	-1.40183 0.8395	-6.92112*** 0.0000	-7.09548*** 0.0000
lnCA	-2.54192 0.1158	-1.83817 0.6616	-5.47483*** 0.0001	-5.97154*** 0.0002
lnRP	-3.24028** 0.0277	-1.25927 0.8781	-2.88908* 0.0589	-4.09239** 0.0164
lnMT	-2.95228* 0.0509	-3.91948** 0.0231	-6.40335*** 0.0000	-6.33971*** 0.0001

Note: ***, ** and * indicate 1%, 5% and 10% significance levels, respectively.

Table 7. *F-Bounds Test*

Test Statistics	Value	Signif.	I (0)	I (1)
		Asymptotic: n = 1000		
F-Statistics	6.604278	10%	2.08	3.00
K	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

The estimated F-statistics value is higher than the I (1) Bound value at all levels of statistical significance, as shown in *Table 7*. This disproves the null hypothesis that there

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is no long-term relationship. Thus, it is established that a long-term relationship exists. After this, we perform the DOLS. The outcome is shown in *Table 8*.

Table 8. *Result of Dynamic Least Square (DOLS)*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnFT	0.019841	0.004991	3.975457	0.0018
lnRP	0.562658	0.202091	2.784181	0.0165
lnMT	-0.19851	0.381189	-0.52075	0.612
lnCA	0.583158	0.10635	5.483405	0.0001
C	-6.76191	2.289445	-2.95351	0.0121
R-squared	0.987862			
Adjusted R-squared	0.971679			
S.E. of regression	0.013991			
Long-run Variance	0.000126			
Mean dependent var	5.657699			
S.D. dependent var	0.083136			
Sum squared resid	0.002349			

Dependent Variable: LNMP, Method: Dynamic Least Squares (DOLS), Included observations: 29, Cointegrating equation deterministic: C, Automatic leads and lags specification (lead=1 and lag=1 based on AIC criterion, max=1), Long-run variance estimate (Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

The findings show that fertilizer, cultivated area, and rural population have a significant positive impact on millet production. A one percent increase in cultivated area, rural population, and fertilizer leads to 0.58%, 0.56%, and 0.01% increase in millet production respectively. The output further shows that fertilizer has less impact on millet production whereas mean temperature has a negative but insignificant impact on production during the study period. Data on precipitation did not fit in the model. So, this variable is ignored in the model. Furthermore, the R squared value (0.98) justifies the strength of the model.

The outcome of DOLS is further confirmed by the use of FMOLS and CCR. The findings are shown in *Table 9* and *Table 10*.

Table 9. *Result of Fully Modified Least Square (FMOLS)*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnFT	0.016404	0.002627	6.244232	0
lnRP	0.534424	0.082634	6.467347	0
lnMT	-0.36592	0.163095	-2.24359	0.0336
lnCA	0.553764	0.064491	8.586652	0
C	-5.63245	0.946761	-5.94918	0
R-squared	0.96006			
Adjusted R-squared	0.953915			
S.E. of regression	0.019765			
Long-run Variance	0.000337			
Mean dependent var	5.654279			
S.D. dependent var	0.092069			
Sum squared resid	0.010157			

Dependent Variable: LNMP, Method: Fully Modified Least Squares (FMOLS), Included observations: 31, Cointegrating equation deterministic: C, Long-run covariance estimate (Pre whitening with lags = 1 from AIC max lags = 1, Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

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Table 10. *Result of Canonical Cointegrating Regression (CCR)*

Variable	Coefficient	Std. Error	t-Statistic	Prob.
lnFT	0.015536	0.003049	5.09486	0
lnRP	0.620653	0.095771	6.480586	0
lnMT	-0.40857	0.260894	-1.56605	0.1294
lnCA	0.557769	0.06858	8.133061	0
C	-6.9901	0.958811	-7.29038	0
R-squared	0.9408			
Adjusted R-squared	0.931692			
S.E. of regression	0.024063			
Long-run Variance	0.000337			
Mean dependent var	5.654279			
S.D. dependent var	0.092069			
Sum squared resid	0.015055			

Dependent Variable: LNMP, Method: Canonical Cointegrating Regression (CCR), Included observations: 31, Cointegrating equation deterministic: C, Long-run covariance estimate (Pre whitening with lags = 1 from AIC max lags = 1, Bartlett kernel, Newey-West fixed bandwidth = 4.0000)

Both the result of FMOLS and CCR are similar to that of DOLS both in sign and significance though there is a slight change in coefficient value. It indicates the strength of the model.

Discussion

According to the results of all three methods (DOLS, FMOLS, and CCR), there is a positive and significant relationship between fertilizer and millet production in Nepal. Oladimeji (2020) and Bewket (2009) also found the same result and agree that fertilizer has a positive relationship with millet production. But Gebreyohannes et al. (2021) contradict the result. However, the minimal impact of fertilizer justifies the fact that millet can be produced in low soil fertility. Similarly, mean temperature showed a negative and insignificant relationship with millet production. However, the study by Hussain et al. (2022) found statistically significant results. Karim et al. (2022) also acknowledged the same but the research of Ma et al. (2022) opposes our result. As millet can be produced with low temperatures and having a favorable cold climate, the temperature might not have significantly impacted millet production during the study period.

There is a significant positive relationship between cultivated area and millet production. The findings are supported by Bonham et al. (2012), Ma et al. (2022), and Lubadde et al. (2016). But it contradicts Gebreyohannes et al. (2021) who believe that only increasing the cultivated land do not increase the production of millet besides that there are a lot of things that can affect millet production. The government study report of the fiscal year 2015/16 Government of Nepal, (2020) shows that the average benefit-cost ratio of improved rainfed millet in selected 5 hilly districts of Nepal is greater than 1.5 (Government of Nepal, 2020). It indicates the possibility of increasing millet production by increasing cultivated area in a hilly region where gross farm income is at a satisfactory level in comparison to cost. As millet production in Nepal is rural based and rural population density is not much high the cultivated area is in significant amount. Such farmland could be commercialized in the coming days. Furthermore, the preparation of a land use map in Nepal for the sustainable and optimal use of land Department of

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Agriculture, (2022) shows the possibility of increased production even with the limited cultivation area.

Rural population has a significant impact on millet production during the study period from 1988 to 2019. A one percent increase in rural population causes a 0.56% increase in millet production. But there seems challenge to increase the rural population in the coming years as urbanization is increasing and rural population growth is minimal in recent years. From 2011 to 2015 rural population growth in Nepal was negative and it has remained near 2% during the study period. Such scenario might create a challenge in millet production in the coming year as millet production is concentrated mainly in rural areas. In developing nations, it is claimed that more than 1.3 billion rural families depend on small-scale farming (Bonham et al., 2012). So, enhancing farming methods Ansar and & Paiman, (2022) in the process of millet production could help to uplift rural farm income in Nepal where poverty is a rural phenomenon.

Conclusion

Millet can be accurately referred to as multipurpose crops because of their nutritive qualities and climate change resistance traits. Realizing its growing importance, the study has tested the determinants of millet production in the landlocked country of Nepal. By using DOLS, FMOLS, and CCR methods for 32 years, the study found a significant positive impact of fertilizer, rural total population, and cultivated area on millet production. The mean temperature did not affect significantly. It might be due to the climate-resistance nature of millet. However, the coefficient of mean temperature is negative showing a negative impact on production.

Nepal, being a climate-vulnerable country, needs to take precaution for climate adaptive practices in the millet-grown area. Brain drains and migration from the rural sector to the urban sector should be discouraged for the enhancement of the production of millet as well as millet cultivated area should be protected. The study suggests for further research on alternative uses of millet in Nepal. The food industries are to be encouraged to use it for enriching nutrients in the food products.

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APPENDIX

Table A1. *Comparing the number of nutrients found in 100 gm of rice, wheat, and other millets*

Crop Name	Protein (g)	Fat (g)	Ash (g)	Crude Fiber (g)	Carbohydrate (g)	Energy (kcal)	Thiamine (mg)	Riboflavin (mg)
Rice	6.8	0.5	0.6	0.2	78.2	362	0.41	0.04
wheat	11.8	1.5	1.5	1.2	71.2	348	0.41	0.1
Sorghum	10.8	3.1	1.6	2	70.7	329	0.38	0.15
Pearl Millet	11.8	4.8	2.2	2.3	67	363	0.38	0.21
Finger Millet	7.3	1.3	2.7	3.6	72	336	0.38	0.21
Foxtail Millet	12.3	4.3	3.3	8	60.9	351	0.42	0.19
Proso Millet	12.5	3.1	1.9	7.2	70.4	364	0.59	0.11
Little Millet	7.7	4.7	1.5	7.6	67	329	0.41	0.28
Barnyard Millet	6.2	2.2	4.4	9.8	65.5	300	0.3	0.09
Kodo Millet	8.3	1.4	2.6	9	65.9	353	0.33	0.1

Source: Muthamilarasan et al. (2015)

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