The Effects of Biofuels on Food Security in Selected Countries

Ebrahim Babakhani, Reza Rostamian, Mostafa Goudarzi

Department of Agriculture Economic, Qaemshahr Branch, Islamic Azad University, Iran

Abstract

Biofuels are produced as replacements for fossil fuels. Nevertheless, these fuels may jeopardize food security. No research has examined the relationship between the production of biofuels and food security in terms of their various dimensions. This study examined the effects of biofuels on food security in several developed and developing countries comprising oil-producing and developed countries. Dimensions of food security were including food availability, food accessibility, food utilization, and food stability. To this end, standard and neo-Malthusian theories combined with the food availability decline (FAD) theory were employed. In addition, the panel generalized method of moments (GMM) was used to estimate the relationships between variables. The results showed that food stability, population growth, and income inequality were measured by the Gini index, and unemployment was significantly higher in developing countries than in developed countries. Conversely, food security, food availability, food accessibility, food utilization, land area, total biofuel production, agricultural credit allocation, and food product prices were higher in developed countries than in developing countries. The increase in biofuel production reduced food security by 0.031%, 0.047%, and 0.064% in all countries, developing and developed countries, respectively. In developing countries, biofuels had a significant impact on food accessibility and food availability. However, biofuels had significant and positive effects on food stability and utilization. In developed countries, biofuels had negative effects on food accessibility, stability, and availability and positive effects on food utilization (0.016%). In conclusion, policies are needed to mitigate the negative effects of biofuels on food security.

Keywords

Biofuels, developing countries, developed countries, food availability, food security.

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Introduction

Historically, nonrenewable fossil resources have driven the development of civilization, where investment growth increased from 4.2% in 2017 to 4.7% in 2018 (Subramaniam, Masron and Azman 2019). However, their applications are restricted due to the emission of air and environmental pollutants (Stolarski et al. 2019). Due to the renewability of the feedstocks, biofuels have been introduced as alternatives to fossil fuels (Brinkman et al., 2020).

Some industrial crops have been used for non-food applications, including fiber production, bioenergy, and industrial products (Jarzebski et al., 2020). Nevertheless, biofuel production necessitates land that can jeopardize food security (Martínez-Jaramillo et. al, 2019). First-generation biofuels are conventional, while subsequent generations are more advanced. However, the third and fourth generations have not yet been commercialized (Mohanty et al., 2021).

Food insecurity is characterized by limited access to safe and nutritious food, whereas food security is represented by all people having physical, social, and economic access to adequate, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (George and McKay, 2019). Indeed, available land and water resources for biofuel production compete with food production (Pachapur et al., 2020). Despite advancements, more than 820 million people are still malnourished, and at least 2 billion fail to receive sufficient nutrients (Ingram, 2020). Moreover, during the 2008 financial crisis, biofuels may have contributed to a 20 to 40% increase in food prices (Mittal, 2008; Sousa et al., 2019). The relationship between population and food supply is one of the most important economic principles. Moreover, the decrease in food security can have destructive effects, health risks, and negative socioeconomic consequences (Abdullah and Akbar 2021).

Some nations, such as those in the Middle East, play a significant role in the global oil and gas market supply. These countries derive most of their income from oil and natural gas resources. However, rapid population growth and changes in zonal climate and the water cycle have increased the need to integrate the planning and design of renewable energy and systems in this area (Nematollahi et al., 2016). It has been reported that water scarcity, drought, and economic growth severely restrict energy production in Middle Eastern nations. This water-food security is primarily impacted by drought, water scarcity, population growth, urbanization, or political unrest (Hameed et al., 2019). On the other hand, natural disasters, such as frequent drought events, water scarcity, and unsustainable intensive agricultural practices, may threaten food security in these nations (Hameed at al., 2020). On the other hand, developed countries are pioneers in producing biofuels. In the United States, ethanol is produced primarily from corn, while in Brazil, it is produced from sugarcane. Moreover, biofuels are mainly obtained from oilseeds in the European Union, particularly in Spain, Germany, and France (Simionescu et al., 2017). In 2016, European countries produced more than one thousand ktoe biofuels (Streimikiene et al., 2019).

The relationship between food security and biofuels has been the subject of numerous studies. A study has evaluated the impact of biofuels on food security in 51 developing countries and found a negative correlation between biofuels and food security (Subramaniam et al., 2020). Other studies have reported a negative correlation between biofuel production and food supply in Colombia (Martínez-Jaramillo et al., 2019), food prices and imports in Ghana (Brinkman et al., 2020), and food security in low- and middle-income countries (Renzaho et al., 2017).

Despite potential food security crises in the Middle East and the global shift toward biofuels, it seemed necessary to investigate the impact of food security and biofuels on food security in oil-producing countries. We were unable to find a study examining the relationship between food security and biofuels on food security in oil-producing and developed countries which considered various food security dimensions. Consequently, the current study examined the relationship between food security and biofuels in the studied countries.

Increased biofuel production increases food prices, resulting in chronic malnutrition (To and Grafton, 2015). Hence, the focus of this study is to further contribute to the literature by empirically analyzing the effect of biofuel production on food security. Another important contribution of this study is that it takes a broader view of the definition of food security. For the reasons stated in the theoretical foundations, this study also aims to separate food security into four dimensions, "food availability"; "food accessibility"; "Food utilization" and "food stability”. Food availability does not rely only on the amount of food within the national borders, which was the main issue of food security in the past, and today it also includes the production (domestic and/or internal supply) and importing the food. Food accessibility refers to physical and economic access to resources in order to provide food items needed by society (Renzaho and Mellor 2010). Food stability mentions the ability to receive food over time. Food utilization is based on the correct use of food. Based on this, the existence of food and access to it does not mean that people's diet is healthy and nutritious (Renzaho and Mellor 2010). Another important issue is comparing the effects of biofuels on food security in different countries of the Middle East and developed countries. The importance of this issue increases when we know that most countries of the Middle East countries have not much attention to this issue due to the abundant sources of fossil fuels.

Materials and methods

In the present study, a standard Malthusian and neo-Malthusian theory emphasizing food insecurity was employed due to the large population compared to the amount of food supply (Malthus et. al., 1992). On the other hand, neo-theory suggests that limited and finite land resources are responsible for insufficient food supply per person. Equation (1) can be utilized to express food security:

$$FS = (POP, AL) \tag{1}$$

Where FS denotes food security, POP represents the population, and AL is arable land.

The Food Availability Decline (FAD) theory was then applied to determine the primary causes of the food shortage (Devereux, 1993). Several studies have found that biofuels impact food supply or production (Ajanovic, 2011; Amigun et. al, 2011; Kgathi et al. 2012) and agricultural credits (Adams and Hunter, 2019). Thus, the equation for this is formulated as follows:

$$FS = (POP, AL, BP, CA, ED) \quad (2)$$

Where *BP, ED*, and *CA* are biofuel production, environmental degradation (*ED*), and agriculture credit, respectively.

Food entitlement decline (FED) theory was incorporated to complete the model. The theory is predicated on the set of alternative commodity bundles that a person can command in a society based on the totality of rights and opportunities that individuals face (Devereux, 1993). Therefore, food demand or consumption is determined by variables such as income inequality (Masters et al., 2013), income (Pingali, 2007), price (Campbell et al., 2016; Koizumi, 2015), and unemployment (Etana and Tolossa, 2017; Loopstra and Tarasuk, 2013). Consequently, the complete model is expressed as follows:

$$FS = (POP, AL, BP, CA, ED, IE, GDP, PRI, UNE \quad (3)$$

Where *IE* denotes income inequality, *GDP* is income, *PRI* represents price, and *UNE* is unemployment.

Subsequently, the model can also be presented as follows;

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + + \beta_9 UNE_{it} + \varepsilon_{it} \quad (4)$$

All variables are then transformed into logarithms. Equation (5) can be rewritten as follows:

$$lnFS_{i,t} = \alpha + \beta lnX_{i,t} + \varepsilon_{i,t} \quad (5)$$

For a more precise assessment of food security, each element must be reported in four dimensions and transformed as follows:

$$FS_{element} = \frac{Country\ Index - World\ Minimum}{World\ Maximum - World\ Minimum} \times 100 \quad (6)$$

The maximum and minimum global values were considered for the United States and Sudan, respectively (World Bank, 2018). Calculations of FS were performed in a range of 0-100 based on the above relationship of minimum food security (Sudan) and maximum food security (USA).

Four separate indices were created for each of the four dimensions. This was completed by calculating each dimension's mean of all element indices. The food availability index (FSAVA) consists of five components; consequently, the index is expressed as the weighted average of these five components, as shown in Equation 7:

$$FS_{AVA} = (FS_{element1} + FS_{element2} + \ldots)/5 \quad (7)$$

It is essential to mention, the weight of each dimension is equalized. All dimensions are homogenized in the range of 0 to 100 before averaging.

Consequently, the final equation for food security is as follows:

$$FS = (FS_{AVA} + FS_{ACC} + FS_{UTI} + FS_{STA})/4 \quad (8)$$

Where FS_{ACC}, FS_{UTI}, and FS_{STA} denote food accessibility, food utilization, and food stability indexes, respectively.

Four dimensions were initially calculated and then divided by four (total dimensions) in the current study. The food security index is reported as a value between 1 and 100, where the higher the value, the greater the level of food security. The FAO food security framework is illustrated in Table 1.

Code	Dimension	Source
	Availability	
AV1	Average dietary energy supply adequacy	FAOSTAT
AV2	Average value of food production	FAOSTAT
AV3	Share of dietary energy supply derived from cereals, roots, and tubers	FAOSTAT
AV4	Average protein supply	FAOSTAT
AV5	Average supply of protein of animal origin	FAOSTAT
	Access	
AC1	Gross domestic product per capita (in purchasing power equivalent)	World Bank
AC2	Prevalence of undernourishment	FAOSTAT
AC3	Depth of the food deficit	FAOSTAT
	Stability	
ST1	Food per capita	FAOSTAT
ST2	Percent of arable land equipped for irrigation	FAOSTAT
ST3	Per capita food supply variability	FAOSTAT
	Utilization	
UT1	Percentage of the population with access to improved drinking water sources	World Bank
UT2	Percentage of the population with access to sanitation facilities	World Bank
UT3	Prevalence of obesity in the adult population (18 years and older)	GHO
UT4	Prevalence of anemia among women of reproductive age (15–49 years)	World Bank

Source: Adopted from FAOSTAT

Table 1: The FAO framework of food security.

In addition to the indices reported in Table 1, several additional indices must be defined, as detailed in Table 2.

Code	Definition/Measurement	Source
POP	Population growth per year	World Bank
ED	CO2 emission based on tonne/metric	World Bank
AL	Land area (total land %)	World Bank
GDP	Gross production in the year 2010 (US dollars)	World Bank
UNE	Unemployment as a percentage of the workforce	World Bank
PRI	Food product price indices	FAOSTAT
BP	Total biofuel based on 1000 barrels/day	IEA and OECD
CA	Agriculture section credit as a proportion of total credits	FAOSTAT
IE	Income inequality in Gini indices	OECD

Source: Adopted from FAOSTAT and World Bank

Table 2: Variable definition and resources.

Panel data methodology was used to estimate our empirical models. The generalized method of moments (GMM) estimation was used to account for potential endogeneity (Equation 9).

$$y_{it} = \alpha y_{it-1} + \beta' X_{it} + \eta_i + \phi_t + \varepsilon_{it} \quad (9)$$

Where y is a dependent variable, x depicts an explanatory variable, η is individual effects or companies fixed, and φ is the effects of time fixed. Subscripts i and t represent the corporation and the time period, respectively.

The first-order difference is an effective method for removing fixed effects, outlined the Equation 10.

$$\Delta y_{it} = \alpha \Delta y_{it-1} + \beta' \Delta X_{it} + \Delta \phi_t + \Delta \varepsilon_{it} \quad (10)$$

Where Δy_{it-1} represents the difference for a dependent variable that correlates with $\Delta \varepsilon_{it}$.

There are inherent issues with the model that must be considered. Consequently, it is necessary to include tool variables in the model, as shown in Equations 11-14.

$$E(y_{it-s}\, \Delta\varepsilon_{it}) = 0 \quad s \geq 2;\ t = 3,4,\ldots,T \quad (11)$$

$$E(X_{it-s}\, \Delta\varepsilon_{it}) = 0 \quad s \geq 2;\ t = 3,4,\ldots,T \quad (12)$$

$$z_i = diag(y_{i1}, y_{i2}, \ldots, y_{it-2}, X_{i1}, X_{i2}, \ldots, X_{it-2}) \quad (13)$$

$$\delta\hat{} = (\beta' z A_N z' B)^{-1} \beta' z A_N z' Y \quad (14)$$

It is necessary to identify model tool variables to estimate the model. A reliable estimator is dependent on non-correlation errors and modifiable tools. To this end, the Sargan test is employed to investigate confirmation tests. In addition, the M_2 statistic examines the second-order serial correlation between sentences. The Sargan test is described in Equation 15.

$$S = \hat{\varepsilon}' z \left(\sum_{i=1}^{N} z_i' H_i z_i\right)^{-1} z' \hat{\varepsilon} \quad (15)$$

In this test, $\varepsilon\hat{} = Y - X\delta\hat{}$, $\delta\hat{}$ is a k × 1 matrix of estimated coefficients, z denotes a matrix of tool variables, and H is a square matrix.

The data were collected from Australia, Austria, Canada, The Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, South Korea, Luxemburg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Chile, Turkey, the UK, United States, Estonia, Israel, Russia, Lithuania, China, Costa Rica, India, Belgium, Romania, Bahrain, Egypt, Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, The United Arab Emirates, and Yemen. Bahrain, Egypt, Turkey, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, The United Arab Emirates, and Yemen were developing and other countries were developed. The data utilized were panel data collected annually from a select population. The data were collected from FAO and World Bank during 2000-2019 and analyzed by Eviews software.

Results and discussion

Descriptive data

The results for the studied variables in the selected countries are provided in Table 3. The average value of the food security index, which is calculated based on the average of four indicators of food availability, food accessibility, food stability and food utilization, is equal to 51.90%. In other words, the food security level of the studied countries is about 52%. The mean of the variable is also equal to 53.198. The highest level of the food security index is 63.778% and the lowest level is 30.301%. The standard deviation for this variable is 8.072%, in fact, the standard deviation shows the amount of dispersion compared to the average. This number indicates that there is 8.072% dispersion compared to the average, which is an average dispersion. By examining the dimensions of food security, it can be seen that the average index of food availability is 42.96%. Similarly, food

Variables	Symbol	Mean	Median	Min	Max	SD
Food security	FS	51.901	53.198	30.301	63.778	8.072
Availability	FSAVA	42.968	44.870	26.555	56.081	8.575
Accessibility	FSACC	65.816	68.744	31.497	85.329	14.042
Stability	FSSTA	25.136	22.495	6.246	53.477	14.215
Utilization	FSUTI	73.068	75.796	38.487	91.854	14.675
Population growth (%)	POP	1.760	1.246	0.164	5.944	1.572
Land area (log)	AL	5.212	5.384	3.386	6.953	0.881
Biofuel production*	BP	2.106	0.000	0.000	16.000	4.206
Credit for agriculture	CA	3.227	1.858	0.059	13.222	3.679
CO2 emission damage	ED	6.395	6.327	4.832	7.464	0.683
Income inequality	IE	32.421	31.800	26.800	41.900	4.447
Gross production	GDP	4.388	4.617	3.095	4.940	0.506
Food price	PRI	92.869	95.635	63.845	112.260	12.269
Unemployment (%)	UNI	5.122	3.905	1.044	13.555	3.452

Note: *1000 barrels/daily

Source: Adopted from findings of the current study.

Table 3: Data for the variables studied in the selected countries.

accessibility and food utilization were 65.861% and 73.068%, respectively. It should be noted that the desired indicators were normalized based on the minimum and maximum dimensions used in the range of zero to 100 percent. By comparing the four indicators, the highest level of food security index in countries is for food utilization. In fact, the values for food utilization in the study countries are close to each other. The lowest amount was for food stability. By examining other indicators, the average percentage of population growth is 1.76%. The highest population growth is 5.944% and the lowest is almost zero. The logarithm of the arable land is also 5.212. Also, the total production of biofuels for the sample countries is 2.106 thousand barrels per day. The lowest amount of biofuel production is zero and the highest amount is 16 thousand barrels. In the same way, the average credit allocated to the agricultural sector is 3.227% in relation to the total credits. The highest credit of the agricultural sector is around 13% and the lowest amount is close to zero.

By examining the logarithm of carbon dioxide emission damage, it can be seen that its average is 6.395. By taking the anti-logarithm, the damage of carbon dioxide emissions is 2.485 billion dollars. Likewise, the average income inequality based on the Gini coefficient index is 32.421%. The highest inequality is 41.9% and the lowest is 26.8%. The average logarithm of GDP per capita for the sample countries is 4.388. The average food price index and unemployment were 92.868 and 122.5%, respectively.

Comparison of developed and developing countries

Based on the results of Table 4, it can be seen that the difference in the average of two groups of Middle Eastern and developed countries for all indicators is significant ($P<0.05$). The average food security index is lower for developing countries in the Middle East. However, the food stability in Middle East countries is higher than in developed countries, which is because of the oil-rich sources. Food availability, food accessibility, and food utilization are more in developed countries. The percentage of population growth, income inequality in the GINI index, and the percentage of unemployment in the developing countries of the Middle East are higher than in developed countries. Also, the total production of biofuel, the percentage of credit to the agricultural sector, the GDP per capita, and the food price index are lower in the developing countries of the Middle East. The land area and carbon dioxide emission damage are almost the same in both groups.

Correlation between variables

Table 5 displays the results of the correlation analysis. The results show a positive and significant correlation between the food security index and each of its dimensions. In addition, there is a significant positive (0.824) correlation between food security and GDP. Similarly, there was a negative and significant correlation between the food security index and land area, income inequality in the GINI index and unemployment percentage.

Variables	Symbol	Symbol	Developing	Developed	T
Food security	FS	FS	47.342	55.321	-14.830**
Availability	FSAVA	FSAVA	37.759	46.874	-16.359**
Accessibility	FSACC	FSACC	56.559	72.759	-18.391**
Stability	FSSTA	FSSTA	33.455	18.897	15.546**
Utilization	FSUTI	FSUTI	60.370	82.591	-29.943**
Population growth (%)	POP	POP	3.014	0.820	25.267**
Land area (log)	AL	AL	5.066	5.322	-3.853**
Biofuel production*	BP	BP	0.104	3.608	-11.963**
Credit for agriculture	CA	CA	2.318	3.908	-5.791**
CO_2 emission damage	ED	ED	6.262	6.496	-4.552**
Income inequality	IE	IE	33.988	31.246	8.471**
Gross production	GDP	GDP	3.988	4.687	-24.753**
Food price	PRI	PRI	90.166	94.896	-5.139**
Unemployment (%)	UNI	UNI	7.039	3.684	14.510**

Note:** indicates significance at the 5% level
Source: Adopted from findings of the current study.

Table 4: Data for variables studied in developed and developing countries.

Variables	FS	FSAVA	FSACC	FSSTA	FSUTI	POP	AL	BP	CA	ED	IE	GDP	PRI	UNI
FS	1.000													
FSAVA	0.708*	1.000												
FSACC	0.881*	0.585*	1.000											
FSSTA	0.217*	-0.142*	-0.079*	1.000										
FSUTI	0.779*	0.590*	0.770*	-0.321*	1.000									
POP	-0.220*	-0.458*	-0.228*	0.530*	-0.539*	1.000								
AL	-0.195*	0.177*	-0.176*	-0.324*	-0.027	-0.299*	1.000							
BP	0.135*	0.282*	0.254*	-0.373*	0.265*	-0.325*	0.382*	1.000						
CA	0.036	0.183*	-0.029	-0.036	0.042	-0.239*	0.311*	-0.015	1.000					
ED	0.238*	0.209*	0.212*	-0.113*	0.359*	-0.299*	0.559*	0.459*	0.020	1.000				
IE	-0.175*	-0.056	-0.238*	0.062	-0.223*	0.121*	0.213*	0.086*	-0.177*	0.222*	1.000			
GDP	0.824*	0.546*	0.927*	-0.152*	0.814*	-0.311*	-0.128*	0.256*	0.034	0.223*	-0.282*	1.000		
PRI	0.110*	0.092*	0.185*	-0.093*	0.114*	-0.205*	0.056	0.146*	0.012	0.247*	-0.003	0.191*	1.000	
UNI	-0.621*	-0.301*	-0.696*	0.066	-0.600*	0.089*	0.242*	-0.120*	-0.004	0.022	0.292*	-0.766*	0.093*	1.000

Source: Adopted from findings of the current study.

Table 5: Correlation between variables.

Moreover, there was a positive and significant correlation between the food security index and biofuels. In the same way, there is a positive and significant correlation between the food security index and carbon dioxide emission damage, GDP per capita, and the food price index. Furthermore, the correlation between each of the food security indicators and other variables is also noticeable in the table. The highest correlation is between GDP and unemployment, which is equal to -76.6%. In estimating the research models, attention should be paid to the correlation of these two variables. The correlation of other independent variables is less than 70% and is not very worrying.

The food security model for the selected countries

According to Table 6, Sargan's test is not statistically significant. Hence, it can be said that the variables defined in the model are valid and the model does not need to define more variables. Moreover, the results show that in the research model, there is autocorrelation of the first degree but not of the second degree. Therefore, it can be seen that the second-order serial autocorrelation problem does not exist in the research models, and the GMM estimator is consistent. Food security has a positive and significant effect on food security with a time lag. Likewise, the coefficient of biofuels is -0.031 and it is significant based on the t-statistic. Indeed,

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.705	0.011	66.403	0.000
Population growth (%)	POP	-0.133	0.018	-7.444	0.000
Land area (log(	AL	0.305	0.104	2.928	0.004
Biofuel production (total)	BP	-0.031	0.009	-3.592	0.000
Agricultural credit (%)	CA	0.036	0.011	3.371	0.001
CO_2 emission damages	ED	0.443	0.142	3.115	0.002
Income inequality for Gini indices	IE	0.006	0.010	0.566	0.571
Gross production of internal per capita (log)	GDP	7.783	0.487	15.986	0.000
Food products indices	PRI	-0.001	0.001	-1.226	0.221
Unemployment (%)	UNI	-0.019	0.003	-5.739	0.000
Sargan test statistic	329.489				
Sargan test probability	0.513				
First-order autocorrelation (P)	-8.60 (0.000)				
Second-order autocorrelation (P)	-1.21 (0.226)				

Source: Adopted from findings of the current study.

Table 6: Food security model based on total food security indices for selected countries.

a one-barrel increase in biofuels leads to a decrease of 0.031 percent in food security. Therefore, it can be said that increasing the use of biofuels reduces food security. Also, the increase in unemployment has a negative and significant effect on food security. In this regard, it is expected that with an increase in the unemployment rate of one percent, the amount of food security will be decreased by 0.019 percent. With an increase of one percent in arable land area, food security is to be increased by 0.305 percent. A one percent increase in credit to the agricultural sector leads to an increase of 0.036 percent in food security. In the same way, an increase of one percent in carbon dioxide emission damage, 0.443 percent, increases food security, which is a positive relationship due to more production and as a result, an increase in pollution emission. As well as a one percent increase in GDP per capita increases food security by 7.783 percent. One percent population growth reduces food security by 0.133 percent. Moreover, income inequality in the GINI index and food price index does not affect food security.

The food security model based on the dimensions of food security for all the selected countries

The food security model was represented using food security dimensions in order to investigate food security dimensions (Table 7). According to the results, the probability of Sargan was greater than 5%, and the defined variables were confirmed. It was unnecessary to supply additional variables. There was a first-order autocorrelation, but no second-order autocorrelation was observed (the probability value is greater than 5%). It can be seen that research models do not include serial autocorrelation. In other words, it is a GMM estimator that is consistent. Also, the results show that in the research model, there is autocorrelation of the first degree, but not of the second degree, because the statistical probability is higher than the 5% error level. Therefore, it can be seen that the problem of second-order serial autocorrelation does not exist in the research models, and indeed the GMM estimator is consistent. Biofuels have a negative and significant effect on the dimensions of food availability, food accessibility, and food stability, but their effects on food utilization is positive and significant ($P<0.01$). The coefficient of influence of this variable on access to food is 0.141 and is significant ($P<0.01$). In fact, income inequality leads to increased access to food. However, its effect on other indicators is negative and insignificant. By examining the GDP per capita, it can be seen that the increase in the GDP per capita has a negative and significant effect on food availability. It has a positive and significant effect on food accessibility and food stability. It did not have significant effects on food utilization. In the same way, the increase in the food price index reduces food availability but increases the sustainability of food intake. Finally, the unemployment rate has almost the same results as the price index, so it has a negative and significant effect on food accessibility and food stability. It could be attributed to the replacement of capital for more production and higher food security.

$$FSAVA_{it} \text{ or } FSACC_{it} \text{ or } FSSTA_{it} \text{ or } FSUTI_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.738***	19.014	0.416***	3.270	0.674***	22.327	0.936***	73.636
Population growth (%)	POP	0.028	0.309	-0.120	-0.585	-0.030	-0.453	0.119***	5.687
Land area (log)	AL	-0.419	-0.410	1.429	0.342	-1.382	-1.093	-0.034	-0.085
Biofuel production (total)	BP	-0.087***	-7.694	-0.206***	-2.948	-0.102***	-2.986	0.021***	3.094
Agricultural credit (%)	CA	0.068	1.616	0.331**	2.334	0.086*	1.865	0.020*	1.740
CO_2 emission damages	ED	3.089***	4.598	2.144**	2.314	-1.498***	-2.258	1.169***	6.610
Income inequality for Gini indices	IE	-0.021	-0.816	0.141***	2.919	-0.103	-1.279	-0.008	-1.347
Gross production of internal per capita(log)	GDP	-3.927***	-3.390	30.059***	7.539	7.408***	3.229	-0.072	-0.165
Food products indices	PRI	-0.007	-0.911	-0.030**	-2.510	0.027***	2.782	0.000	-0.062
Unemployment (%)	UNI	-0.043	-1.241	-0.448***	-5.014	0.057**	2.539	-0.046***	-5.999
Sargan test statistic	FS(-1)	28.156		19.027		178.444		23.809	
Sargan test probability	POP	0.351		0.796		0.178		0.530	
First-order autocorrelation (P)	AL	-2.405 (0.016)		-9.307 (0.000)		-6.406 (0.000)		-2.417 (0.016)	
Second-order autocorrelation (P)	BP	-0.023 (0.981)		-0.815 (0.415)		-1.309 (0.190)		-0.072 (0.943)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 7: Food security model based on four dimensions.

The food security model for developing countries

The results of the food security model in developing countries are displayed in Table 8. The probability of the test for Sargan confirms sufficient variables ($P<0.05$). The results exhibit autocorrelation of the first order. Since the probability is less than 1%, first-order autocorrelation is established. No second-order autocorrelation exists. In other words, it is a GMM estimator that is consistent.

Food security has a positive and significant effect on the food security index with a time lag. In the same way, the coefficient of biofuels is -0.047 based on the t-statistic ($P<0.01$). In this regard, one unit increase in biofuels leads to a decrease of 0.047% in food security. It can be said that increasing the use of biofuels reduces food security. According to the findings, biofuels had positive effects on food security indices. The population growth coefficient was -0.047 and significant ($P<0.01$). Indeed, the increase in population growth as the size of one unit decreased by 0.047% in food security. An increase of 1% in the land area could increase food security by 1.557%. Additionally, the increased 1% credit to the agriculture sector increased food security by 0.081%. Thus, agricultural credits create opportunities for increased output.

Regarding CO_2 emissions, an increase of one unit in CO_2 emission damages increases food security by 1.393%. In addition, population growth (1 unit) reduces food security by 0.047%. The increase in Gini by 1% reduces food security by 0.031%. The increase in the cost of food products had a negative impact on food security. Gross domestic product per capita and unemployment had an insignificant effect on food security in developing countries.

Food security model based on food security dimensions for developing countries

Table 9 shows the results for the food security model based on the food security dimensions. Based on the results, the Sargan probability was greater than 5%. It indicates that the defined variables are confirmed, and no other variables need to be specified. In addition, there was a first-order autocorrelation, while no second-order was observed. Furthermore, serial autocorrelation failed to occur in the research models. In other words, it is a GMM estimator that is consistent. Based on the data in Table 9, lag in food security dimensions has a positive effect on the dependent variables ($P<0.01$). The results also showed that biofuels had significant effects on food accessibility and food availability. However, biofuels

$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$					
Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.745	0.024	31.668	0.000
Population growth (%)	POP	-0.047	0.016	-2.973	0.003
Land area (log(	AL	1.557	0.464	3.352	0.001
Biofuel production (total)	BP	0.530	0.141	3.746	0.000
Agricultural credit (%)	CA	0.081	0.021	3.775	0.000
CO_2 emission damages	ED	1.393	0.089	15.682	0.000
Income inequality for Gini indices	IE	-0.031	0.009	-3.363	0.001
Gross production of internal per capita (log)	GDP	-0.265	0.560	-0.473	0.637
Food products indices	PRI	-0.007	0.002	-4.562	0.000
Unemployment (%)	UNI	-0.011	0.014	-0.795	0.427
Sargan test statistic	139.142				
Sargan test probability	0.815				
First-order autocorrelation (P)	-5.410 (0.000)				
Second-order autocorrelation (P)	-0.186 (0.853)				

Source: Adopted from findings of the current study.

Table 8: The food security model for developing countries based on total food security indices.

$FSAVA_{it}$ or $FSACC_{it}$ or $FSSTA_{it}$ or $FSUTI_{it}$ = $= \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$									
		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.891***	82.040	0.606***	22.806	0.614***	21.889	0.957***	175.767
Population growth (%)	POP	-0.085***	-15.408	-0.076***	-3.109	-0.217***	-3.296	0.037**	2.201
Land area (log)	AL	1.145***	3.567	-0.592	-0.892	1.854	1.054	-0.459	-1.131
Biofuel production (total)	BP	-0.205**	-2.371	-0.900***	-2.732	3.080***	5.325	0.037***	9.155
Agricultural credit (%)	CA	-0.052***	-9.499	0.169***	11.642	0.395***	4.318	-0.016***	-2.649
CO_2 emission damages	ED	0.386***	14.670	-3.929***	-7.612	0.487	1.082	-0.049	-0.228
Income inequality for Gini indices	IE	-0.062***	-14.739	-0.026	-0.684	0.045	1.383	0.003	0.447
Gross production of internal per capita(log)	GDP	-1.618***	-16.120	21.917***	15.090	-4.473*	-1.794	0.358	0.831
Food products indices	PRI	-0.012***	-17.987	0.020***	4.251	0.009	1.312	-0.003***	-4.168
Unemployment (%)	UNI	-0.011***	-5.834	0.049***	2.330	0.111***	3.925	0.086***	9.281
Sargan test statistic	FS(-1)	161.236		144.888		139.750		144.139	
Sargan test probability	POP	0.349		0.689		0.805		0.826	
First-order autocorrelation (P)	AL	-3.223 (0.001)		-7.048 (0.000)		-4.015 (0.000)		-1.985 (0.047)	
Second-order autocorrelation (P)	BP	0.210 (0.834)		-0.442 (0.658)		-0.147 (0.883)		-0.775 (0.438)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 9: Food security model based on four dimensions in developing countries.

demonstrated positive and significant effects on stability and utilization.

Population growth has a negative and significant effect on food availability, food accessibility, and food stability in Middle Eastern countries. Also, it has a positive and significant effect on food availability in the Middle East countries. The land area has a positive (1.145) and significant effect on the food availability in the Middle East countries (P<0.01) that could be attributed to the lack of arable land in the Middle East. However, it does not affect other dimensions of food security.

Credit to the agricultural sector has a positive and significantly affects food accessibility and stability in the Middle East countries, and it has a negative and significant effect on food availability and food utilization. It is expected that by increasing the amount of credit in the agricultural sector by 1%, access to food will be increased by 0.16%. The reason for such a difference can be justified by the low efficiency of the use of facilities. In fact, although agricultural credit increases accessibility and sustainability, due to the low efficiency of credit use, in Middle East countries, food availability and utilization decrease.

The increase in agricultural credits increases food availability and stability, while low credit efficiency reduces availability and utilization. Damage caused by CO_2 emissions has a positive impact on food availability (0.386) and a negative impact on food availability in developing countries (-3.929). In addition, it had no significant impact on the other dimensions. The results of the Gini indices indicated that the variable had a negative impact on food availability (-0.062). In fact, income inequality reduces food availability but does not significantly affect the other dimensions. In terms of gross domestic product, the increase in gross production reduces food availability and stability but does not affect food consumption in developing countries. A one-percent increase in the unemployment rate leads to a 0.011% decrease in food access.

The food security model for developed countries

Table 10 shows the results of the food security model in developed countries. Since the Sargan value was 0.457, the variables were sufficient, and no other variables needed to be specified. The results show a first-order autocorrelation. Thus, a first-order autocorrelation is observed since the probability is less than 1%. No second-order autocorrelation exists. This indicates it is a GMM estimator that is consistent.

The results showed that an increase in the production of biofuels decreases food security indices. The coefficient for biofuels was 0.064%, thus, increased biofuels reduce food security. In addition, the utilization of biofuels reduces food security. This rate was higher in developed countries than in developing countries. Increased CO_2 damage by 1% increases food security by 2.244% in developed countries. The population growth coefficient was 0.275%, which is higher than that of developing countries. An increase of one percent in carbon dioxide emission damage increases food security by 2.244 percent, which is a stronger positive relationship in developed countries than in developing countries in the Middle East. The increase in population growth had a 0.275% effect on food security, which is greater in developed countries. Unemployment reduces food security in developed countries by 0.087%. Other variables had no significant effect on food safety.

$$FS_{it} = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

Variable	Symbol	Regression coefficient	Standard Error	T-statistic	Probability
Lag of food security	FS(-1)	0.670	0.030	22.574	0.000
Population growth (%)	POP	-0.275	0.076	-3.642	0.000
Land area (log(	AL	0.240	0.151	1.585	0.114
Biofuel production (total)	BP	-0.064	0.011	-5.719	0.000
Agricultural credit (%)	CA	0.027	0.049	0.541	0.589
CO_2 emission damages	ED	2.244	0.953	2.355	0.019
Income inequality for Gini indices	IE	-0.025	0.038	-0.652	0.515
Gross production of internal per capita (log)	GDP	11.207	2.493	4.495	0.000
Food products indices	PRI	-0.004	0.004	-1.000	0.318
Unemployment (%)	UNI	-0.087	0.044	-1.990	0.047
Sargan test statistic	163.271				
Sargan test probability	0.457				
First-order autocorrelation (P)	-7.338 (0.000)				
Second-order autocorrelation (P)	-1.046 (0.296)				

Source: Adopted from findings of the current study.

Table 10: Food security model based on total food security indices for developed countries.

Food security model based on food security dimensions for developed countries

Table 11 illustrates the results of the food security model based on the dimensions of food security. The Sargan test probability is not significant, which means that the defined variables are confirmed. The first and second-order autocorrelation conditions are also satisfied. Furthermore, no serial autocorrelation was observed in the research models. In other words, it is a consistent estimator of GMM. Based on the data in Table 11, the lag in food security dimensions had positive and significant effects (P<0.01). Biofuels had a negative impact on food accessibility, stability, and availability and a positive impact on food utilization (0.016%). The effects of biofuels on food security were not similar in developing and developed countries. This effect was negative and positive for developed and developing countries, respectively. Population growth negatively affected the availability and accessibility of food in developing countries. Also, credit to the agricultural sector has a positive and significant effect on food stability in developed countries, and it has a negative and significant effect on food utilization. It does not affect food availability and accessibility. Credits had positive and negative effects on food stability and utilization, respectively. CO_2 emission damages had a positive effect on food availability, accessibility, and utilization of food and a negative effect on food stability in developed countries (-3.506) (P<0.01). The Gini index has had a negative impact on the availability and use of food in developed countries. Income inequality led to a decrease in food availability and food utilization. The increase in unemployment had negative effects on food accessibility and stability and positive effects on food utilization.

Discussion

This study examined the impact of biofuels on food security in selected developing and developed countries. Indeed, some agricultural products used by humans can be used to produce biofuels that threaten food security. The increase in biofuel production leads to an increase in the consumption of animal and vegetable oils, cereals, and other agricultural products. These countries mainly produce fossil fuels and do not use agricultural products to produce biofuels. Consequently, it had less impact in developing countries. The results indicated that biofuels had negative effects on food availability. The production of biofuels requires water, workers, and other resources, which impact food availability. The results showed that the coefficients were lower

$$FSAVA_{it} \text{ or } FSACC_{it} \text{ or } FSSTA_{it} \text{ or } FSUTI_{it} = \\ = \alpha_1 + \beta_1 POP_{it} + \beta_2 AL_{it} + \beta_3 BP_{it} + \beta_4 CA_{it} + \beta_5 ED_{it} + \beta_6 IE_{it} + \beta_7 GDP_{it} + \beta_8 PRI_{it} + \beta_9 UNE_{it} + \varepsilon_{it}$$

		FSAVA		FSACC		FSSTA		FSUTI	
Variable	Symbol	Coefficient	T	Coefficient	T	Coefficient	T	Coefficient	T
Lag of food security	FS(-1)	0.881***	43.130	0.768***	22.430	0.669***	28.508	0.948***	231.603
Population growth (%)	POP	-0.095***	-3.370	-1.406***	-5.671	0.310*	1.738	0.015	1.319
Land area (log)	AL	-0.355***	-3.906	0.824**	2.147	-36.725	-0.937	-0.077**	-2.256
Biofuel production (total)	BP	-0.033**	-2.219	-0.168***	-6.700	-0.061*	-1.838	0.016***	7.519
Agricultural credit (%)	CA	0.003	0.234	0.048	0.931	0.208**	2.424	-0.018***	-3.221
CO_2 emission damages	ED	0.707***	2.940	4.917***	2.999	-3.506***	-3.088	0.706***	5.667
Income inequality for Gini indices	IE	-0.061***	-3.622	0.129	1.649	-0.072	-1.106	-0.010***	-2.821
Gross production of internal per capita(log)	GDP	-0.153	-0.466	20.457***	5.916	-1.631	-1.513	0.550*	1.798
Food products indices	PRI	0.004***	2.125	-0.077***	-5.847	0.058***	5.969	-0.001**	-2.121
Unemployment (%)	UNI	0.003	0.410	-0.502***	-5.791	-0.040**	-2.150	0.098***	12.593
Sargan test statistic	FS(-1)	147.865		146.503		147.337		160.661	
Sargan test probability	POP	0.780		0.803		0.805		0.581	
First-order autocorrelation (P)	AL	-3.407 (0.001)		-9.032 (0.000)		-5.828 (0.000)		-2.217 (0.027)	
Second-order autocorrelation (P)	BP	-0.584 (0.559)		-0.844 (0.399)		-1.381 (0.167)		-1.098 (0.272)	

Note: *, **, *** show significant differences at 90.00%, 95.00% and 99.00%, respectively
Source: Adopted from findings of the current study.

Table 11: Food security model based on four dimensions in developed countries.

in developing countries, which can be attributed to lower biofuel production in developing countries. Our results demonstrated the negative effects of biofuels on food accessibility in developing and developed countries. Biofuels increase the land area for agricultural production, resulting in a lower supply of food products and a lower price. From another perspective, the competition of biofuels with food production will lead to less availability and increased food costs for the poor. In particular, net buyers of food and energy will suffer from parallel increases in food and energy prices. As net buyers of food and energy, the poorest of the poor could be particularly vulnerable. These fuels have also had a negative impact on food stability in all studied countries. Indeed, biofuels reduce land area and, therefore, food stability. The FAO (2018) report states that the production of biofuels can have negative effects on food security, which can further endanger situations of poverty and hunger. The impact of biofuels on food security has been evidenced by previous studies (Koizumi, 2015). Biofuel production negatively impacts food security and can provide opportunities for agricultural development (Koizumi, 2015). The concept of utilization refers to the human ability to obtain food and nutrients. It includes other concepts such as water supply, energy, health, and medical services. Biofuels have also been reported to have negligible effects on price due to low price effects (Westhoff, 2010). The increase in biofuel production leads to an increase in the consumption of animal and vegetable oils, cereals, and other agricultural products. The use of agricultural products to produce oils jeopardizes food security. Biofuels have an impact on food availability, it should be said that biofuel production prevents food accessibility because it is one of the factors affecting the price of food goods. There is a correlation between the development of biofuels and the increase in commodity prices, exacerbating food insecurity in developing countries. A study has suggested that palm oil prices increase when Malaysian and/or Indonesian produce biodiesels from palm oil (Ghosh et. al., 2019). In this regard, increasing biofuel production also reduces the stability of food intake. The results showed lower production of biofuels in Middle Eastern countries. These countries mainly have abundant sources of fossil fuels and do not use agricultural products to produce biofuels. It must be stated that biofuels are not important in Middle-East countries due to the abundant oil and gas resources. On the other hand, the production of biofuels in middle-east countries is very low and therefore cannot have tangible effects on food security.

The estimation results of the model show that the variable of food security lag in the long term has a positive and significant effect on the characteristics of food security in developing and developed countries. It means that changes in the level of food security do not end in just one period; rather, the increase of this index can affect the improvement of food security in the following periods. Population growth reduces food security and the need for food. A shortage of food materials causes an increase in the population of food materials. The results are similar to those reported in the literature (Masters et al. , 2013; Tian et al., 2016; Subramaniam et al., 2020). Population growth leads to an increase in the consumption of water and land. The findings are consistent with previous studies that showed the importance of the global food supply and the production of ruminant milk and meat. Molotoks et al. (2021) indicated that countries with projected declines in population growth had higher food security, while countries with projected rapid population growth had the worst impact on food security by 2050. Moreover, climate change scenarios affected future crop yields, population growth is the main driver of change in malnutrition prevalence for more than 159 countries. Hall et al. (2017) showed that rapid population growth will be the main cause of widespread food insecurity and malnutrition across Africa. So that its effect is greater than the effects of climate change on reducing food safety.

Agriculture credits had significant and positive effects on food availability, while they had negative effects on food use attributable to the low efficiency of the credits. Agriculture credits increase accessibility and stability, but poor credit efficiency reduces availability and utilization. Credits for the agricultural sector offer opportunities for more produce. In this direction, a positive and significant effect of access to credit on food security among maize farmers in Nigeria was confirmed (Ogunniyi et al., 2021). In this study, it was found that if the government allocates a suitable budget, there is a possibility of improving food safety and security at the household level.

In terms of CO_2 emissions, a one-unit increase in CO_2 emissions damage increases food safety in developing countries by 1.393%. Meanwhile, Hardy et al. (2003) showed that the doubling of carbon dioxide leads to a 10-50% loss of agricultural land and a decrease in the global yield of key food crops between 10-70%. In such a way that with the reduction of agricultural lands and with the prediction of the increase of human migration, more challenges and risks will occur in connection with the successful cultivation of crops and breeding of domestic animals. As a result, these conditions will be a threat to food security.

The negative relationship between the Gini index and food security in developing countries can also be followed. The results of some studies have also shown that income inequality exacerbates food insecurity with the continuation of poverty and the expansion of inequalities in terms of affordability to receive food (Subramaniam, et. al., 2019).

Another finding is the negative relationship between unemployment and food safety in developing countries. Etana and Tolossa (2017) concluded that the prevalence of food insecurity is higher among households headed by unemployed people and that these households are unable to cope with the increase in food prices in Ethiopia. However, the relationship between unemployment and food safety in developed countries has not been statistically significant. Certainly, this effect is negative and significant in relation to food accessibility, food utilization, and food stability indicators and consistent with the theory.

Conclusion

The effects of biofuels on food security have been considerable in developed and developing countries. The utilization of biofuels is low in developing countries compared to developed countries, which could be attributed to fossil sources in each country. Based on the results, it can be hypothesized that Middle Eastern countries can use third and fourth-generation biofuels to improve environmental issues and increase food security. In these countries, the energy requirement is low due to low oil wells. In conclusion, biofuels have a negative effect on food security, but this effect is positive and significant on food security in the Middle East countries. Consequently, the use of biofuels to reduce greenhouse gas emissions is recommended due to a lack of conflicts present in this region. Considering the fact that in developing countries, a large share of the income of the poor is allocated to food consumption. Therefore, the increase in food prices due to the expansion of biofuels will increase the vulnerability of these people. Meanwhile, with the opening of trade, it is possible to earn money from the higher prices of goods, which can lead to the possibility of direct sales to factories by small owners. In such a situation, it is expected that a favorable environment for increasing employment in farms and factories will be provided. Moreover, it is recommended to increase the existing technology of biofuel production, and weigh the benefits of producing these products against its possible bad consequences. Furthermore, increasing employment opportunities along with supporting policies for poor households can improve the economic status of households while increasing the development of human capital and ultimately lead to guaranteeing food security. However, our study is also faced with limitations. In this study, we did not consider the price of oil as a factor affecting food security, and our reason was that the Middle East countries mostly have a lot of oil and this cannot be effective for them. Using oil prices for developed countries compared to developing countries will complicate the results. We also estimated the results regardless of the fact that some countries in the Middle East use limited biofuels, and we did not distinguish between countries, which is a limitation, and our suggestion is to pay attention to this issue in future studies.

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Corresponding author:
Reza Rostamian
Department of Agriculture Economic, Qaemshahr Branch, Islamic Azad University, Qaemshahr, Mazandaran Province, Qolzam Kola, Jadenezami Rd, CR9J+WPV, Iran
E-mail: rezarostamian74@gmail.com

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