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Development of the cultivated mushroom market from the standpoint of time series sustainability

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Abstract. The article deals with the issues of sustainable development of the world market of cultivated mushrooms. The authors of the article have studied the time series of the world gross value, world volumes of imports and exports, the world price index for cultivated mushrooms and truffles in order to analyze their growth and dynamics. The results of calculations carried out using the statistical database of the Food and Agriculture Organization of the United Nations from 1961 to 2022 showed that the indicated time series are non-stationary. The gross value of mushroom production increased 70 times during the study period, the volume of imports increased 98 times, the volume of exports increased 93 times, and the producer price index doubled. The price index for cultivated mushrooms and truffles is stable without sharp fluctuations. The authors reveled shifts in a series of world gross value of mushroom production in 2000, 2009, 2011. Additive emissions, level shifts and temporary changes were found in the dynamics of world imports and exports.

1 Introduction

Issues of sustainable development of various branches of agriculture need to be considered due to global climate change, food, water and energy security, reduction of biological diversity, problems of access and sharing of natural resources [1-6].

The interpretation of the category "sustainable development" currently varies widely in different fields of science [7-12]. Generally it characterizes the property of various systems in the presence of a number of exogenous influences to maintain an equilibrium position for a long period of time.

The sustainable development of the market of cultivated mushrooms can be defined as its ability to restore and, possibly, increase the characteristics of the product offer and consumer demand for cultivated mushrooms, which were inherent to it before the period of external influence, in a fairly short period of time.

The market of cultivated mushrooms is a unique market, which combines the medicinal benefits of products, food culture, exotic flavors and an environment that is alternative to many traditional food products. However, according to researchers, there is a risk of consumers rejecting dangerous, harmful, in their opinion, food that does not bring benefits [13-15]. Cultivated mushrooms are a rich source of protein food, dietary fiber and minerals

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[16-18]. At the same time, the production of cultivated mushrooms is a high-tech, science-intensive production that requires a constant search for scientific research in the integration of biology, mycology, mechanical engineering, automation, which makes it possible to predict the volume of production with a high probability, manage the crop and justify the financial and economic parameters of production [19-23].

2 Materials and methods

The article assessed the stability of the development of the cultivated mushroom market from the standpoint of the stability of time series - the presence of the necessary trend of the studied statistical indicator, which is under the influence of unfavorable conditions.

The study used data from the following time series of the Food and Agriculture Organization of the United Nations (FAOSTAT) statistical database: world gross value of cultivated mushrooms and truffles (at constant prices 2014-2016, thousand US dollars), world imports and exports mushrooms and truffles (in tons) from 1961 to 2021, mushroom and truffle price index (data price index for 2014-2016 is taken as 100) from 1991 to 2022.

To test the stationarity of these time series, the extended Dickey-Fuller test implemented in the R statistical package was used, and the autocorrelation coefficients were calculated.

The time series data was used in a growth model to measure the trend of these variables. According to the study [24], the use of linear growth rates (LGR) has limitations when comparing growth rates between separate periods. Therefore, it is more appropriate to use the compound annual growth rate (CGR) to describe the dependencies. To determine the trend function and the subsequent assessment of growth rates, a semi-logarithmic function was chosen [25, 26]:

$$\ln y = \beta_0 + \beta_1 x + \varepsilon \tag{1}$$

where y – an investigated dependent variable, x – an independent variable, β_0, β_1 – model parameters, ε – a mistake. The parameter β_1 shows a proportional change in y for a given absolute change in the factor, with an increase in the factor by one, the dependent variable will increase by $100\beta_1$%. Wherein

$$\beta_1 = \ln(1+r) \tag{2}$$

where r is a growth rate.

The authors used Chow's test [27] to check the stability of the trend time series model. The test statistic has a Fisher distribution and is calculated by the formula

$$F_{\text{Чоу}} = \frac{[RSS_0-(RSS_1+RSS_2)]/k}{(RSS_1+RSS_2)/(n_1+n_2-2k)} \sim F(n_1+n_2,(n_1+n_2-2k) \tag{3}$$

where k – a number of model parameters, n_1 – a sample size for the period 1, n_2– a sample size for the period 2, RSS_1 – a period residual sum of squares 1, RSS_2 – a period residual sum of squares 2, RSS_0 – a sample residual sum of both squares.

To determine the outliers in the time series, the authors used the approach of Chung Chen and Long-Mu Liu [28]. An iterative procedure for detecting and adjusting for additive emissions (AO), level shift (LS), temporal changes (TC), and innovation emissions (IO) was implemented to obtain estimates of model parameters and emissions effects.

3 Research results

The first step of the study was to test the studied series for stationarity using the Dickey-Fuller test. The results of the calculations (Table 1) show that the time series of the world

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gross production value, the world volume of imports and exports, and the price index for mushrooms and truffles are not stationary.

Table 1. Results of testing time series for stationarity

Time series / p-value for	world gross value of mushroom and truffle production	world imports of mushrooms and truffles	world exports of mushrooms and truffles	price index for mushrooms and truffles
levels of series	0.9012	0.6109	0.9049	0.9854
the first level differences of the series	0.5372	0.2246	0.1121	0.1360

The nonstationarity of the considered time series is also confirmed by the calculations of the autocorrelation coefficients (fig. 1-4).

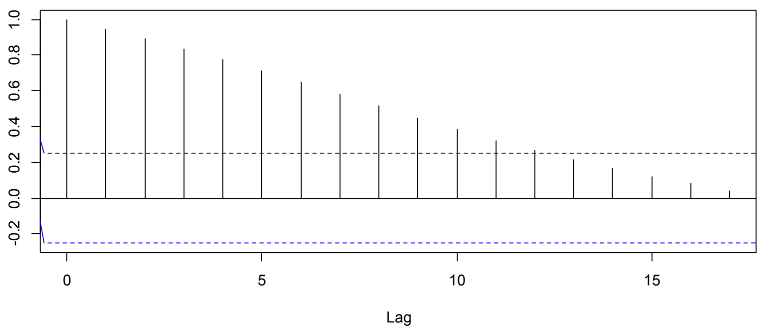

Fig. 1. Correlogram of the world gross value of mushroom and truffle production

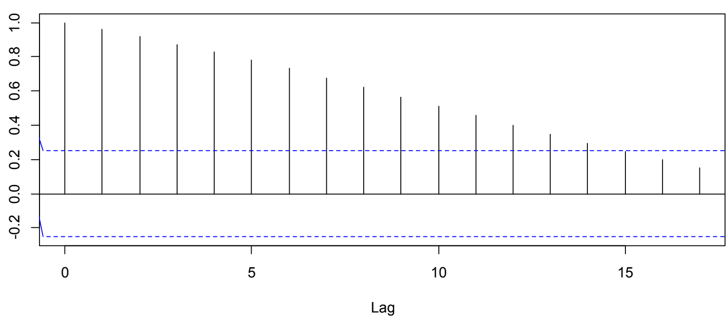

Fig. 2. Correlogram of world imports of mushrooms and truffles

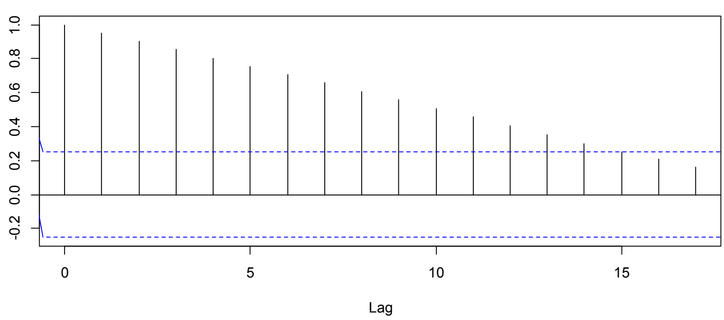

Fig. 3. Correlogram of world exports of mushrooms and truffles

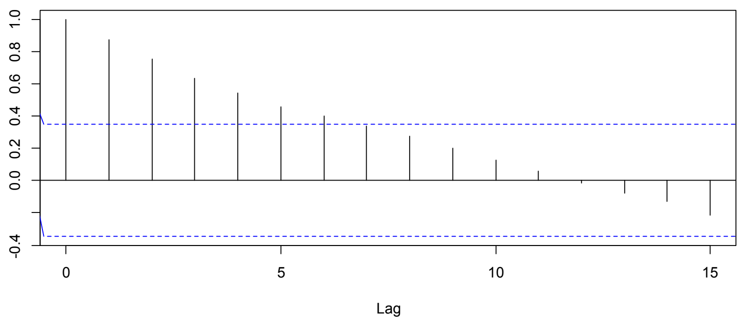

Fig. 4. Correlogram of the price index for mushrooms and truffles

The study has shown that the world gross value of cultivated mushrooms and truffles, the world volume of imports and exports of mushrooms and truffles from 1961 to 2021, the price index for mushrooms and truffles from 1991 to 2022 increased significantly (Table 2-5). Thus, the gross value of mushroom production increased from 664,161 thousand US dollars in 1961 to 4,6814,991 thousand US dollars in 2021 (an average annual growth rate is 14.7%), the volume of imports also increased from 7,357 tons in 1961 to 722,011 tons in 2021 (average annual growth rate is 15.9%) and exports from 8394 in 1961 to 784518 tons in 2021 (average annual growth rate is 15.8%), the producer price index also increased from 65.1 in 1991 to 130.2 in 2022 (CAGR 2.3%).

Table 2. Moving averages and indices of gross value of cultivated mushrooms and truffles (constant 2014-2016 prices, US$ thousand)

Year	Moving average over a three-year period	Index	Year	Moving average over a three-year period	Index
1962	702673.7	100.0	1992	3816448.3	104.6
1963	737401.3	104.9	1993	4029177.3	105.6
1964	789016.7	107.0	1994	4156675.7	103.2
1965	836357.7	106.0	1995	4346051.0	104.6
1966	900629.7	107.7	1996	4504593.0	103.6
1967	948753.3	105.3	1997	4836533.0	107.4
1968	989873.3	104.3	1998	5213738.3	107.8
1969	1038640.3	104.9	1999	7098452.0	136.1
1970	1113940.7	107.2	2000	9237344.3	130.1
1971	1239430.7	111.3	2001	11590877.7	125.5
1972	1352127.3	109.1	2002	12943741.7	111.7
1973	1449003.3	107.2	2003	14289713.3	110.4
1974	1497659.3	103.4	2004	15890311.7	111.2
1975	1534791.3	102.5	2005	17379386.3	109.4
1976	1594165.7	103.9	2006	19130502.7	110.1
1977	1692611.3	106.2	2007	21073531.3	110.2
1978	1816786.7	107.3	2008	23491319.7	111.5
1979	1914226.3	105.4	2009	25766924.3	109.7
1980	1971188.3	103.0	2010	28757280.3	111.6
1981	2021052.0	102.5	2011	31916986.3	111.0
1982	2070605.0	102.5	2012	34958536.0	109.5
1983	2200046.7	106.3	2013	36917744.3	105.6
1984	2343837.0	106.5	2014	38479608.0	104.2
1985	2502342.0	106.8	2015	40024451.7	104.0
1986	2614004.0	104.5	2016	41553831.0	103.8
1987	2754548.3	105.4	2017	42585299.0	102.5

1988	2933858.0	106.5	2018	43557941.7	102.3
1989	3163226.3	107.8	2019	44524117.7	102.2
1990	3392726.3	107.3	2020	45653509.3	102.5
1991	3647587.3	107.5			

Table 3. Moving averages and indices of world imports of cultivated mushrooms and truffles (in tons)

Year	Moving average over a three-year period	Index	Year	Moving average over a three-year period	Index
1962	8259.3	100.0	1992	129955.0	109.6
1963	9196.7	111.3	1993	147782.8	113.7
1964	10426.0	113.4	1994	163279.5	110.5
1965	12793.3	122.7	1995	179097.9	109.7
1966	15194.0	118.8	1996	194433.8	108.6
1967	15200.3	100.0	1997	218472.4	112.4
1968	14819.0	97.5	1998	241924.9	110.7
1969	14119.0	95.3	1999	270318.1	111.7
1970	13776.7	97.6	2000	299594.9	110.8
1971	15050.3	109.2	2001	320556.1	107.0
1972	15886.3	105.6	2002	348663.2	108.8
1973	19285.0	121.4	2003	376332.7	107.9
1974	21041.3	109.1	2004	411717.7	109.4
1975	21756.7	103.4	2005	428220.7	104.0
1976	21441.0	98.5	2006	436688.0	102.0
1977	20159.0	94.0	2007	466512.3	106.8
1978	22475.0	111.5	2008	495143.0	106.1
1979	24291.0	108.1	2009	538526.0	108.8
1980	25874.0	106.5	2010	558255.0	103.7
1981	25549.0	98.7	2011	580409.0	104.0
1982	27228.3	106.6	2012	598407.0	103.1
1983	35428.3	130.1	2013	621277.7	103.8
1984	46063.3	130.0	2014	656465.0	105.7
1985	56309.7	122.2	2015	664904.5	101.3
1986	64441.0	114.4	2016	672706.8	101.2
1987	74769.3	116.0	2017	672026.8	99.9
1988	84203.7	112.6	2018	687266.6	102.3
1989	96532.7	114.6	2019	699647.2	101.8
1990	105528.7	109.3	2020	710266.4	101.5
1991	118587.0	112.4			

Table 4. Moving averages and indices of world exports of cultivated mushrooms and truffles (in tons)

Year	Moving average over a three-year period	Index	Year	Moving average over a three-year period	Index
1962	9323.7	100.0	1992	131632.7	118.5
1963	10052.0	107.8	1993	159258.3	121.0
1964	11261.3	112.0	1994	174395.3	109.5
1965	13881.7	123.3	1995	188662.0	108.2
1966	16788.0	120.9	1996	194815.7	103.3
1967	17104.7	101.9	1997	212461.2	109.1
1968	16507.0	96.5	1998	234078.1	110.2
1969	14650.3	88.8	1999	266664.7	113.9
1970	13489.0	92.1	2000	306851.2	115.1
1971	13973.7	103.6	2001	332671.6	108.4

1972	15026.0	107.5	2002	353993.0	106.4
1973	17355.7	115.5	2003	371473.7	104.9
1974	19648.3	113.2	2004	390755.0	105.2
1975	21714.3	110.5	2005	403309.7	103.2
1976	22557.0	103.9	2006	422611.7	104.8
1977	21667.0	96.1	2007	457469.0	108.2
1978	20060.3	92.6	2008	492446.7	107.6
1979	18650.7	93.0	2009	519603.7	105.5
1980	18354.3	98.4	2010	527810.0	101.6
1981	19079.7	104.0	2011	547725.7	103.8
1982	22115.3	115.9	2012	562288.0	102.7
1983	28121.3	127.2	2013	590645.2	105.0
1984	38263.3	136.1	2014	617544.0	104.6
1985	49124.0	128.4	2015	634667.8	102.8
1986	59116.3	120.3	2016	655151.8	103.2
1987	67888.3	114.8	2017	674829.6	103.0
1988	76478.3	112.7	2018	705062.1	104.5
1989	87266.3	114.1	2019	725601.4	102.9
1990	95469.3	109.4	2020	751465.5	103.6
1991	111096.7	116.4			

Table 5. Moving averages, price indices and producer price index trend for cultivated mushrooms and truffles

Year	Moving average over a three-year period	Indices	Trend	Year	Moving average over a three-year period	Indices	Trend
1992	65.1	100.0	101.0	2007	87.5	105.8	102.2
1993	66.6	102.3	101.0	2008	89.2	101.9	102.3
1994	68.5	102.8	101.1	2009	89.6	100.5	102.4
1995	71.7	104.8	101.2	2010	90.4	100.9	102.5
1996	73.6	102.6	101.3	2011	92.8	102.7	102.6
1997	74.2	100.8	101.4	2012	96.0	103.4	102.7
1998	72.3	97.5	101.5	2013	97.7	101.8	102.8
1999	70.7	97.8	101.6	2014	98.9	101.3	102.8
2000	70.6	99.8	101.6	2015	100.0	101.1	102.9
2001	72.1	102.2	101.7	2016	101.3	101.3	103.0
2002	73.9	102.4	101.8	2017	105.5	104.1	103.1
2003	75.7	102.5	101.9	2018	109.8	104.1	103.2
2004	76.9	101.6	102.0	2019	115.7	105.3	103.3
2005	79.1	102.9	102.1	2020	119.8	103.5	103.4
2006	82.7	104.4	102.2	2021	125.0	104.3	103.5

The results of the calculations show that the semi-logarithmic model of the gross value of cultivated mushrooms and truffles is significant at the level 5% (F_{calc}=4,76, $P_{b_1} = 0{,}037$).

The stability of the growth parameters of the gross value of the production of cultivated mushrooms and truffles was tested using the Chow test. In 2000, there was a significant increase in this indicator by 85% compared to 1999. As a result of applying the test for structural changes at the point of 2000, the value of $F_{Чоу}$ = 65.471, *p-value* = 5.499e-09, therefore, the hypothesis of the absence of structural changes is rejected.

A similar study for the series of world imports and exports of cultivated mushrooms and truffles also shows that there is enough evidence to say that there is a structural break point in the data. (F_{import} = 25.877, $p\text{-}value_{import}$ = 5.074e-06; F_{export} = 18.516, $p\text{-}value_{export}$ = 4.285e-05).

Chung Chen and Long-Mu Liu's method was used to determine other emissions in the series of gross production value of cultivated mushrooms and truffles. The authors have identified three level shifts (in 2000, 2009, 2011). This confirms the conclusion about the structural shift obtained using the Chow test.

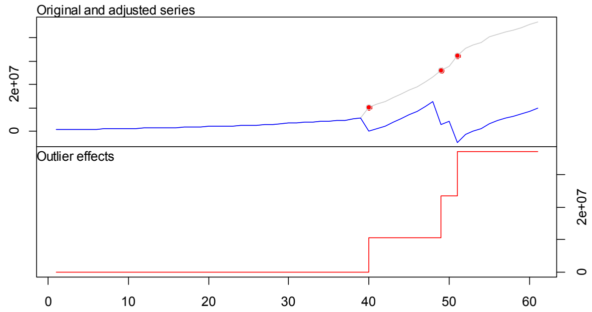

Fig. 5. Identification of emissions in the world gross value of mushroom and truffle production

No outliers were found in the mushroom and truffle price index time series.

In the time series of world imports of cultivated mushrooms and truffles, additive emissions were found in 2002, 2007, 2010, 2012, 2015, a level shift - in 2009, 2016, temporary changes - in 2006.

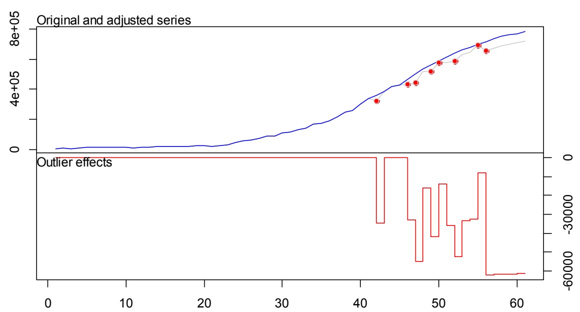

Fig. 6. Identification of outliers in the series of world imports of cultivated mushrooms and truffles

In the time series of world exports of cultivated mushrooms and truffles, additive emissions were found in 1991, 2001, 2004, 2006, 2008, 2020, a level shift - in 2011, temporary changes - in 1995, 1997, 2016. The most significant were the emissions of 2006, 2012, 2016 (the modulus of t-statistics is 13.805, 12.144, 12.725, respectively).

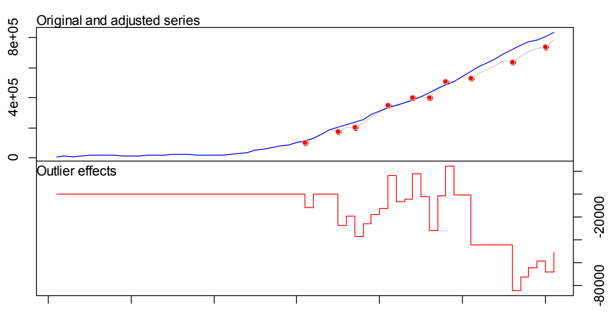

Fig. 7. Identification of outliers in the series of world exports of cultivated mushrooms and truffles

4 Results

The analysis carried out has shown that the time series of the world gross value of production, the world volume of imports and exports, and the price index for mushrooms and truffles are non-stationary. The price index for cultivated mushrooms and truffles is stable, without sharp fluctuations. Three level shifts were identified in the gross production value series of cultivated mushrooms and truffles, several additive emissions, level shifts and time changes were found in the time series of world imports and exports.

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