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ENERGY PRODUCTIVITY OF THE TOMATO GREENHOUSE PRODUCTION

ENERGETSKA PRODUKTIVNOST PROIZVODNJE PARADAJZA U OBJEKTIMA ZAŠTIĆENOG PROSTORA

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ABSTRACT

The aim of this research was to define tomato greenhouse production regarding the energy consumption in order to find the critical points in the energy flow, that can be eliminated or their influence reduced by choosing the adequate type of construction, production technology and culture that will be produced. Energy parameters were determined for four different greenhouse constructions. On the basis of tomato yield, production output and the energy input (fuel, electricity, straw, fertilizer, plant protection chemicals, water, human labor, technical systems), specific energy input, energy output-input ratio and energy productivity were estimated. Results show that the lowest energy consumption was obtained for gutter connected greenhouse with two bays, 21.96 MJ/m^2. The highest energy consumption was measured for the tunnel structure, 26.87 MJ/m^2. The highest tomato yield was obtained in multi-span greenhouse with thirteen bays, 35.81 kg/m^2. As for the energy parameters, the highest energy input was measured for the tunnel structure, 1.55 MJ/kg while the lowest was obtained in multi-span greenhouse with thirteen bays, 0.65 MJ/kg. The highest energy ratio was calculated for the multi-span greenhouse with thirteen bays, 1.23 as well as the highest energy productivity, 1.55 kg/MJ.

Key words: *tomato, greenhouses, energy, energy productivity.*

REZIME

Cilj ovog rada je bio da se definiše proizvodnja paradajza u zaštićenom prostoru sa aspekta potrošnje energije kako bi se uočila kritična mesta u energetskom bilansu proizvodnje i kako bi se utvrdilo da li se izborom konstrukcije objekta zaštićenog prostora može uticati na energetski bilans proizvodnog sistema. Energetski bilans je utvrđen za četiri tipa konstrukcije objekata zaštićenog prostora. Na osnovu prinosa paradajza, energetskog inputa i energetskog outputa određeni su specifični energetski input, energetski odnos i energetska produktivnost. Rezultati pokazuju da je najniža potrošnja energije po jedinici površine ostvarena u objektu sa dva bloka, 21,96 MJ/m^2 dok je najviša potrošnja energije izmerena u objektu tunel tipa, 26,87 MJ/m^2. Najviši prinos paradajza ostvaren je u blok plasteniku sa trinaest blokova, 35,81 kg/m^2. Kada se pogleda energetski bilans, najviši energetski input utvrđen je za objekat tunel tipa 1,55 MJ/kg a najniži za blok plastenik sa trinaest blokova 0,65 MJ/kg. Najviši energetski odnos je zabeležen kod blok objekta sa trinaest blokova, 1,23 kao i najviša energetska produktivnost, 1,55 kg/MJ.

Ključne reči: *paradajz, plastenici, energija, energetska produktivnost.*

INTRODUCTION

Greenhouse production is still among the most energy–consuming branches of agriculture. In the Serbia region, greenhouse energy consumption is 15–20% higher compared to the countries with warmer climate. Producers are faced with high cost of the operations involved in greenhouse production processes such as climate control (*Karadžić, 2005*), fertilizing and irrigation. This is the reason why an optimal combination of energy inputs that will make this production more energy efficient, needs to be found. Tomato is one of the most common vegetable used in human nutrition around the world. It is used for fresh consumption, conservated in some way or as a material for the food processing industry. It is also said that tomato is the most profitable vegetable variety and one of the most widely consumed vegetable crops in the world, with an estimated 99.4 million t of tomatoes being produced worldwide each year (*Chapagain and Wiesman 2004*). Serbia is a part of South-eastern Europe that has a good agricultural potential. In the 2007 (*Statistical office of the republic of Serbia 2008*) Serbia used 5 053 000 ha as agricultural land from which 3 299 000 ha considered as arable land. Vegetable production took 9.1% of the total arable land with production in the open filed. One of the most common vegetable in this region is tomato and it is grown on, around 20 566 ha in the open filed with average yield of 8.3 t/ha. Concerning the greenhouse production Serbia has 10 000 ha under plastic cover greenhouses and 80 ha under glass-houses. The most common vegetable grown in greenhouses is tomato (more than 50%) followed by lettuce, cucumber and pepper. Tomato is grown in open filed as well as in greenhouses. Concerning the greenhouse production, tomato in Serbia is still grown in non-heated greenhouses that enable two up to three week earlier harvesting compared to open filed production. In the open filed, according to *Dasgan et al.* (2004) tomato production is not considered a great problem because solar radiation and temperature are adequate for pollination and fertilization. If tomato is grown in heated greenhouses harvesting can start in April. The reasons why tomato is rarely grown in heated greenhouses are high energy inputs for the production and higher investments in heating systems and high-yielding varieties (*Stevens et al. 1994, Djevic et al. 2008, Babić et al. 2004*). However, there are researches that shows that using double PE inflated folia can reduce energy for heating in early tomato production for 30 up to 40% (*Athanasios et al. 1997; Nelson 2003*) thus leaving this direct energy input under 10% share in the total energy consumption which is very important concerning the energy situation in the World today. Indirect energy use through chemicals, specially through fertilizers, also plays very important role in vegetable production (*Chapagain and Wiesman 2004*). The share of fertilizers in total energy consumption for the open-filed grown species can reach 30% (*Ortiz-Canavate 1999*). As for the greenhouse production the numbers are similar (*Hatirli et al. 2006*). There are reports that tomato production is very intensive in sense human labor engagement (*Bechar et al. 2007*). Since there are a few results about the compare of open-filed and greenhouse vegetable production that confirm that greenhouse production is more intensive in sense of yield and energy consumption compared to open-filed production we thought that it would be interesting to see if production technology influences on yield of different vegetables and what is the influence of different greenhouse construction on vegetables yield and energy use. The other reason may be a potential one. There are reports on temperature rising and UV indexes also. These results are supposed to help in suggesting whether plastic covered greenhouses can act as protective surroundings during summer tomato production in South-eastern Europe region. Since the tomato plays an important role in the human health, the quality of the nutritional components of this major crop fruit of particular concern to producers throughout the world. This topic raises many questions mostly based on ecology, economy and energy issues. Serbian agriculture is having similar problems like other developing countries (*Sonmez and Sari, 2006, Trejo-Perea et al. 2009*). The problems mostly arise regarding registration and monitoring of agricultural producers and their product quantity and quality. This leads to economical and ecological problems, mostly related to fertilizer and other chemicals application that farmers are facing with. The aim of this paper was to analyze energy flow patterns in greenhouse tomato production regarding different types of construction in order to evaluate its influence on energy consumption, energy ratio and energy productivity.

MATERIAL AND METHOD

Influence of greenhouse construction on energy consumption was estimated for four different double plastic covered greenhouses. For the research a tunnel type, 5.5 x 24 m covered with 180 µm PE UV IR outside folia (Figure 1), a gutter connected plastic covered greenhouse 21 x 250 m and with 50 µm inner folia and 180 µm outside folia (Figure 2), a multi-span greenhouse 4 x 8 m wide and 51 m long with 50 µm inner folia and 180 µm outside folia (Figure 3a) and a multi-span greenhouse 13 x 12 m wide and 67.5 m long, with 50 µm inner folia and 180 µm outside folia (Figure 3b) were used.

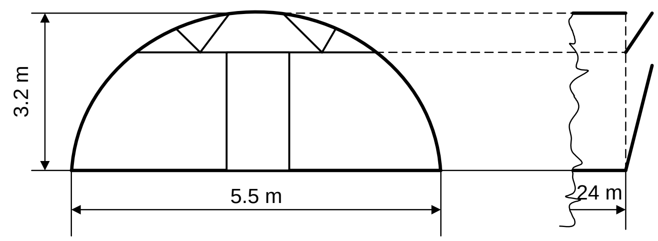

Fig. 1. Tunnel structure covered with double inflated folia, GH1

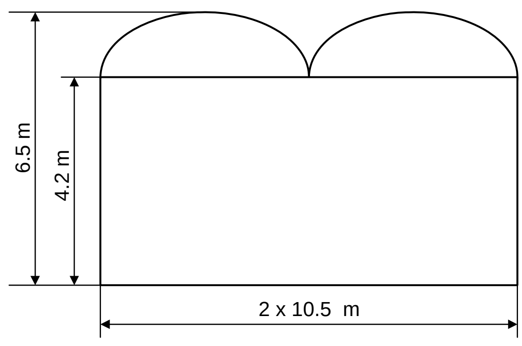

Fig. 2. Gutter-connected greenhouse covered with double inflated folia, GH2

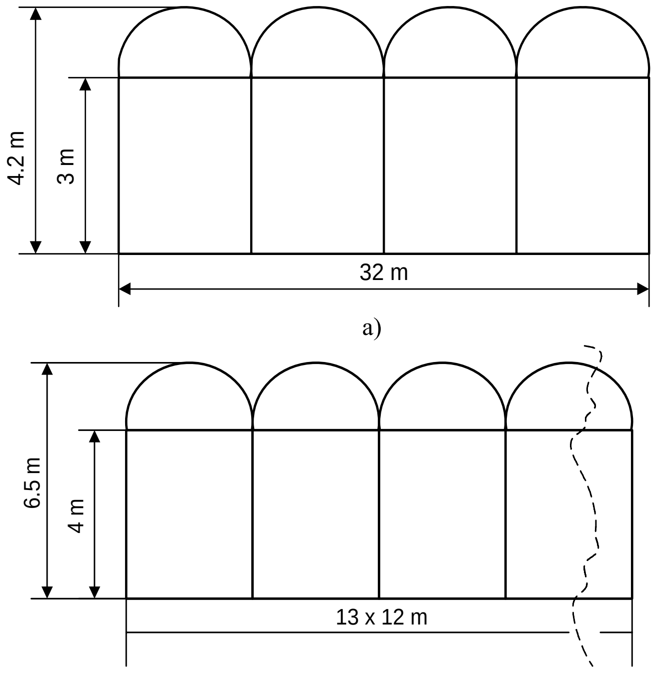

Fig. 3. Multi-span greenhouses covered with double inflated folia, GH3 and GH4

The experiment was carried out at a private property near Novi Sad (Serbia) on 19°51E altitude and 45°20N latitude and at a private property near Jagodina (Serbia) on 21°16E altitude and 44°1N latitude. The method used for the energy efficiency analysis (*Ortiz-Cañavate, 1999, Djevic and Dimitrijevic, 2009, Hatirli et al., 2006, Ozkan et al., 2007, Mani et al., 2007, Khan and Singh, 1996, Canakci and Akinci 2006*) is based on the energy input analysis (definition of direct and indirect energy inputs), calculation of the energy consumption for a given plant production and the energy efficiency. On the basis of tomato production output and the energy input, specific energy input, energy output-input ratio and energy productivity were estimated as follows:

$$EI = \frac{\text{energy input for production [MJ/m}^2\text{]}}{\text{output [kg/m}^2\text{]}} \tag{1}$$

$$ER = \frac{\text{energy value of production [MJ/m}^2\text{]}}{\text{energy input for the production [MJ/m}^2\text{]}} \tag{2}$$

$$EP = \frac{\text{production [kg/m}^2\text{]}}{\text{energy input for the production [MJ/m}^2\text{]}} \tag{3}$$

whre is: EI - Energy input/kg of product, ER - Energy out/in ration, EP - Energy productivity

The energy inputs were calculated by multiplying the material input with the referent energy equivalent. Energy equivalents for different material inputs as well as for the tomato output were obtained from different sources (*Enoch, 1978, Ortiz-Canavate and Hernanz, 1999, Badger, 1999*). Tomato was planted in the greenhouses in April 2008 and harvested from July 2008. 2.8 plants/m^2 were planted in all greenhouses. Production technology was based on soil preparation with rotary hoe (in GH1 and GH2), fertilizer application prior to planting and, during the vegetation period, application of pesticides and fungicides and irrigation.

Statistical analysis included the linear regression model. The parameter that was used to describe differences in constructions was the greenhouse covering / production surface ratio.

RESULTS AND DISCUSSION

A parameter that can be used to compare the energy consumption for different greenhouse constructions is the specific energy input, MJ/m^2. This parameter showed different values for different greenhouse constructions (tab. 1). The lowest value was calculated for the gutter-connected greenhouse (21.96 MJ/m^2). The other greenhouses had 5.42 - 22.36 % higher energy consumption, compared to the gutter structure. The structure of the consumed energy is given in table 2. It can be seen that share of direct energy input in total energy consumption varied from 6.96% (multi-span greenhouse GH4) to 25.68% (gutter-connected structure, GH2). In the gutter-connected the share of direct energy use is higher due to straw consumption that was used for the soil structure improvement since in the tunnel structure and gutter-connected greenhouse tomato was grown on the soil while in the multi-span greenhouses rot substrate was used.

Table 1. Energy consumption for tomato production in the greenhouses

	Tunnel structure, GH1		Gutter connected structure, GH2		Multi-span structure, GH3		Multi-span structure, GH4	
Direct energy inputs	Quantity	Energy	Quantity	Energy	Quantity	Energy	Quantity	Energy
Diesel, l	3.96	189.29	70.00	3346.00				
Electricity, kWh	6.55	78.60	2492.07	8971.50	771.68	2788.85	4998.38	17994.17
Straw, kg			1050.00	17294.00				
Indirect energy inputs								
Nutrients								
Nitrogen, kg	25.42	2000.55	625.23	49206.00	257.32	20251.08	1724.80	135741.80
Phosphorus, kg	11.55	200.97	327.75	5702.90				
Potassium, kg	30.03	411.41	817.40	11198.00	593.20	8126.84	3942.40	54010.88
Plant protection chemicals								
Pesticides, kg	0.03	5.97	0.58	115.42	1.41	280.59	8.16	1623.84
Fungicides, kg	0.27	24.84	3.26	299.92	8.53	784.76	35.54	3269.68
Insecticides, kg								
Water, m^3	22.63	203.67	900.50	8104.50	44.00	396.00	247.00	2223.00
Technical systems, h	0.60	7.84	5.20	67.91				
Human labor, h	108.00	333.20	5600.00	10976.00	3770.00	7389.20	14742.00	28894.32
Total, MJ		3546.44		115281.50		40017.00		2437586.00
Total, MJ/m^2		26.87		21.96		24.52		23.15

Table 2. The share of the energy inputs in overall energy consumption for the greenhouses

Energy input	Share of energy the inputs in overall energy consumption, %			
	Tunnel structure, GH1	Gutter-connected structure, GH2	Multi-span structure, GH3	Multi-span structure, GH4
Fuel for technical systems	5.34	2.90		
Electricity	4.76	7.78	6.96	7.38
Straw		15.00		
Nitrogen	56.41	42.68	50.61	55.69
Phosphorus	5.66	4.95		
Potassium	11.60	9.71	20.31	22.16
Fungicides	0.70	0.26	1.96	1.34
Pesticides	0.17	0.10	0.70	0.67
Water	5.74	7.03	0.99	0.91
Technical systems	0.22	0.06		
Human labor	9.40	9.53	18.47	11.85
Total	100	100	100	100

The highest share in total energy consumption in tunnel structure had fungicides (32.8%) while in gutter-connected and multi-span structures human labor had the highest share and had varied form 19.75% up to 33.25%. Results in the literature (*Hatirli et al., 2006, Ozkan et al., 2007, Enoch, 1978*) show that highest share in total energy consumption have diesel fuel, human labor and fertilizers. In this case, the fertilizers had the highest share in energy bilance of the tomato production. Their share varied from 57.34 to 77.85%. As for the human labor the, it varied from 9.4 to 18.47% and it was higher in case of multi-span greenhouses. The energy output was calculated based on the energy value for tomato and obtained yield (tab.2). The highest yield was calculated for multi-span greenhouse GH4 (31.39 kg/m^2) and the lowest for the tunnel (17.36 kg/m^2). It can be seen that tomato energy output was 42.63 - 106.28% higher in gutter and multi-span greenhouses compared to the tunnel structure.

Based on the measured energy inputs and the energy output, parameters for energy analysis were calculated (tab. 4). It can be seen that different values were obtained for different greenhouse structures regarding basic energy parameters. The higher values of energy input per kg of product were obtained for the tunnel structure compared to the gutter and multi-span structures. The highest energy input per kg of product was calculated for the tunnel structure, GH1, 1.55 MJ/kg, and the lowest value for this parameter was calculated for the multi-span greenhouse GH4, 0.54 MJ/kg. It can be seen that he specific energy input was

42.58 - 65.16% lower in the gutter-connected and multi-span greenhouses than in the tunnel structure. Energy output-input ratio had also showed different values for different greenhouse structures. Gutter-connected and multi-span greenhouses had 73.08 - 136.54% higher energy ratio compared to tunnel structures.

Table 3. Tomato yield and energy output for the greenhouses

	Yield, kg	Specific yield, kg/m^2	Energy output, MJ	Specific energy output MJ/m^2
Tunnel structure, GH1	2291.52	17.36	1833.22	13.89
Gutter-connected structure, GH2	129980.00	24.76	103984.00	19.81
Multi-span structure, GH3	51224.00	31.39	40979.00	25.11
Multi-span structure, GH4	377080.00	35.81	301664.00	28.65

Energy productivity also showed lower values for the tunnel structure. Lowest energy productivity was calculated for the tunnel, 0.65 kg/MJ. The multi-span greenhouse GH4 was calculated to be the structure with highest energy productivity of 1.55 kg/MJ. In average, energy productivity in gutter-connected and multi-span greenhouses was 73.85 - 138.46% higher than in the tunnel. All these parameters show that there should be advantage in energy consumption and energy productivity in using greenhouse structures that have a lower covering material surface / production surface ratio. In order to see if the previously showed differences in energy parameters are influenced by the greenhouse construction, statistical regression analysis was used. The covering material surface / production surface ratio was used as a parameter for describing the greenhouse construction (tab. 4).

Table 4. Parameters for the statistical analysis

Greenhouses	Covering material surface / production surface	Specific energy input, MJ/kg	Energy ratio	Energy productivity, kg/MJ
Tunnel, GH1	1.91	1.55	0.52	0.65
Gutter connected structure, GH2	1.62	0.89	0.90	1.13
Multi-span structure, GH3	1.44	0.78	1.02	1.28
Multi-span structure, GH4	1.30	0.54	1.23	1.55

After importing these data in Microsoft Excel data analysis tool pack, Eqs. 4, 5 and 6 were obtained. These equations gave relations between the calculated energy parameters and the greenhouse specific greenhouse volume. In the case of energy input per kg of product the applied statistical method of linear regression showed that there is a strong correlation between specific energy input and greenhouse construction (92.74%). Equation obtained (eq. 4) gives relation between these two parameters and shows that the decreasing of energy consumption should be expected with the greenhouses with the lower covering material surface / production surface ratio.

$$y = -1.3 + 1.48\,x \tag{4}$$

If the energy ratio is analyzed it can be concluded that there is a strong correlation dependence between this parameter and greenhouse construction (98.16%). The correlation coefficient was estimated to be significant. Regression equitation shows that energy ratio will be higher in conditions of greenhouse structures that have a lower covering material surface / production surface ratio (eq. 5).

$$y = 2.7 - 1.14\,x \tag{5}$$

Similar results were obtained for the energy productivity. Analysis showed that there is a strong correlation between energy productivity and greenhouse type of construction (98.6%). Regression equitation shows that energy productivity will be higher in conditions of greenhouse structures that have a lower covering material surface / production surface ratio (eq. 6).

$$y = 3.38 - 1.42x \tag{6}$$

Presented results lead to the conclusion that in the sense of lowering specific energy input and having energy productivity higher, greenhouse structures with lower covering material surface / production surface ration should be used. The reason for this kind of tendencies can be searched in the more uniform microclimatic conditions in the gutter connected and the multi-span greenhouse. The obtained results can be helpful in suggesting producers what kind of greenhouse structures should they use in order to have a better energy efficiency, energy productivity and lower energy input per kg of product.

CONCLUSIONS

In the study, the energy input and output for different greenhouse construction in tomato production were analyzed. The results of investigation indicate that in the total greenhouse energy consumption, direct and indirect energy inputs have approximately the same share. The specific energy consumption showed different values for different greenhouse constructions. Lowest value was obtained for the gutter-connected greenhouse and the highest for the multi-span greenhouse with the thirteen bays. Higher yield were obtained in the gutter and multi-span greenhouses compared to tunnel structures, due to better climatic conditions and better utilization of the fertilizer. The multi-span greenhouses also showed lower energy input per kg of product compared to the tunnel structure. The linear regression models were estimated as significant and had shown that the greenhouse structure has a significant influence on energy input, energy efficiency and productivity. The results show that lower covering material surface / production surface ratio can influence a lower energy input per kg of product, higher energy ratio and better energy productivity. Additionally, it can be concluded that the energy efficiency can also be higher with gutter-connected and multi-span greenhouses. Further research will include more detailed investigations on characteristics of plastic covers and their influence on energy consumption. In order to investigate different growing mediums and their influence on energy consumption different plant species and production technologies will also be included. The results will be used for creating a model for optimal choice of greenhouse construction and covering material regarding energy consumption and energy efficiency.

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