Effectiveness of wastewater treatment from the fruit and vegetable industry in the vertical flow-type constructed wetlands

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Abstract. The purpose of the work was to determine the effectiveness of wastewater treatment from the fruit and vegetable industry in constructed wetlands supported by a bio-preparation. An increase in the efficiency of organic substance purification expressed as BOD_5 and COD by 8% in deposit with the addition of bio-preparation in relation to the control bed (without the addition of bio-preparation), was found. The efficiency of the total suspension, total nitrogen and total phosphorus increased respectively by 19.5%, 10%, and 27% in relation to the bed without addition of bio-preparation. Constructed wetlands treatment plant ensures high removal of organic compounds expressed as BOD_5 and COD, as well as guarantees reduction in the concentration of nitrogen and phosphorus compounds.

1 Introduction

There is less and less clean water that is necessary for life, yet the demand for water is not decreasing. We use it in industry, agriculture and municipal economy. The problem of water environment pollution and water consumption also applies to the food industry. Difficulties are also caused by the variable amount of water used at various stages of technological processes, e.g. during washing and processing of raw materials. In large food processing enterprises that have a decisive influence on the environment status, practices in the field of water, sewage and waste management meet the basic recommendations and requirements of environmental protection [1]. The situation is different in the case of small local processing plants without access to collective sewage systems, in which production depends on the availability of products (i.e. fresh fruits and vegetables). Due to the use of fresh, organic crops (fruits and vegetables) considered more healthy and valuable, more and more plants of the fruit and vegetable industry are located on areas with low population density or dispersed buildings. Although the amount of wastewater discharged is small, they require treatment to the same extent as larger settling units [2]. The solution for wastewater management for small fruit and vegetable processing plants are the constructed wetlands [3–7]. Therefore, the research was undertaken to determine the effectiveness of

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wastewater treatment from the fruit and vegetable industry in constructed wetlands supported by bio-preparation.

2 Characteristics of the fruit and vegetable industry

The fruit and vegetable industry is characterized by seasonality of production, which depends on the type of production, availability of raw materials, but also the demands [6–9]. In Poland fruit and vegetable market (2016), assessed that the total production of fruit products amounted to 1 110 thousand tons in the season 2015/16, compared to 1 085 thousand tons in the previous season [14]. Increase in the production of processed products made from strawberries, cherries, currants and apples was greater than production of plum and raspberry preserves. Changes in the production were in line with shaping of the harvest and supply of individual fruit species. Total production of drinking juices, nectars and beverages increased from 1.60 to 1.65 million tons (Table 1) [14].

Table 1. Production of juices, nectars as well as fruit, vegetable and fruit-vegetable beverages (in millions of liters) in Poland in 2010–2016 [14].

Specification	2010	2011	2012	2013	2014	2015	2016
Total drinking juices	**544.10**	**452.70**	**418.20**	**480.90**	**541.40**	**595.00**	**625.00**
- made of citrus fruits	149.70	104.90	91.70	105.20	111.00	130.00	135.00
- apple	102.50	74.60	76.20	107.50	139.00	160.00	175.00
- other single-species juices	69.10	58.90	49.10	52.70	57.80	65.00	70.00
including: tomato juices	39.60	36.60	30.30	33.80	37.70	38.00	39.00
- mixed juices	222.80	214.30	201.20	215.50	233.60	240.00	245.00
Nectars	**215.80**	**167.10**	**167.00**	**157.50**	**172.70**	**180.00**	**185.00**
Beverages	**776.80**	**879.40**	**801.30**	**788.70**	**806.40**	**825.00**	**830.00**
Total	**1536.70**	**1499.20**	**1386.50**	**1427.10**	**1520.50**	**1600.00**	**1640.00**

Due to the increasing production of juices, fruit and vegetable beverages in food industry companies since 2013, the amount of sewage is increasing as well [15–19]. Therefore, the issues of environmental protection in the fruit and vegetable industry mainly concern water and sewage management [20–23]. They are generated at various stages of technological processes, e.g. during washing and processing of raw materials. The amount and type of wastewater from food processing is largely determined by the industry, technology and seasonality of production as well as the amount of water consumed [8, 10]. In fruit and vegetable processing, the largest amount of water is used for raw materials washing (sugar beets and potatoes), that may in some plants constitute up to 50% of the total water consumption [14]. Most of these plants do not analyze water consumption at various stages of production processes [24, 25]. Fruit and vegetable processing is characterized by a production campaign, which occurs mainly from June to October [26]. In the case of wastewater from fruit and vegetable processing plants, they may constitute about 18% of the discharged wastewater amount, of which 45% was discharged to the surface water, 39% to the municipal sewage system, and 15% to the ground or tanks [27]. Due to the specificity and diversity of the raw material processed, wastewater from the fruit and vegetable industry is difficult to characterize [4, 9, 12, 13]. According to Nawirska, Soroko, and Puchlik, wastewater generated in fruit and vegetable plants is characterized by high content of carbohydrates and minerals and variable composition depending on the raw material being processed or the season of the year [9, 12, 13]. Their composition is also affected by the processes of washing and disinfection of production lines. The washing process causes transfer of solid, colloidal and dissolved contaminants, dependent on the type of raw material processed, as well as technological process used. At the same time, difficult to determine amounts of various cleaning and disinfecting components enter the wastewater. Depending on the location of sewage generation, following processes can be distinguished: washing the raw material, cleaning, peeling, blanching, cooling (cooling water), filling. Composition and amount of sewage also depend on: type, quality, setting and size of washing devices, type and origin of raw material [9, 13]. Wastewater generated during the production of fruit concentrates is characterized by a reaction in the range from 5.80 to 9.40 and COD value from 1 030.00 to 5 630.00 $mgO_2 \cdot dm^{-3}$ [28]. In plants producing a diverse assortment, e.g. salads, purees, marinades, the range of acidity may be from 4.90 to 7.70, and the value of COD is from 5 260.00 to 270.00 $mgO_2 \cdot dm^{-3}$. These quantities depend on the production technology and currently processed product range [28]. Wastewater from fruit and vegetable processing is low in nitrogen, and organic matter is the main contaminant. According to literature data, the BOD_5 value ranges from 500.00 to 5000.00 $mgO_2 \cdot dm^{-3}$, and during the intensive production periods, it exceeds even 5 000 $mgO_2 \cdot dm^{-3}$ [13, 27, 29]. These values are higher than in domestic wastewater [30, 31].

3 Material and methods

The paper presents the research upon the treatment of wastewater from the fruit and vegetable industry in constructed wetlands supported by a bio-preparation, which were carried out in 2015–2016. The bed was fed with sewage from a small processing plant, which was created in the period from V to X (2015 and 2016) during washing, sorting and production of fruit and vegetable juices. The hydraulic load was 0.01 m^3/m^2d. One of the deposits was additionally supported by the bio-preparation BIO AQUA PUR CODE 106 from EKOB-TBA Ltd., that ensures the maintenance and reactivation of biological wastewater treatment plants. It is intended for wastewater with high COD parameters containing cellulose. It enriches biological beds with microorganisms to improve their degradation properties. Samples of raw and treated wastewater were collected every 14 days from May 2015 to October 2016. The sewage treatment plant consists of a retention reservoir and two parallel systems consisting of ground and plant beds with common reed (*Phragmites australis*). Ground and plant beds have the dimensions of a square - 75 × 75 centimeters and depth of 80 centimeters. They were built in a system with the sub-surface vertical flow of sewage. The beds have four layers of filling, from the top: layer I (sand 0–2 mm, 0.15 m), layer II (gravel 2–8 mm, 0.15 m), layer III (sand 8–20 mm, 0.20 m), layer IV (stones 20–80 mm, 0.15 m), on which the common reed (*Phragmites australis*) was planted. In the raw and treated sewage samples taken, in accordance with mandatory methodology, the following parameters were determined:

- COD – dichromate method according to: PN-74/C-04578.03,
- BOD_5 – manometric method using Oxi-Top Standard system,
- $P_{tot.}$ – spectrophotometric method according to: PN-EN ISO 6878:2006,
- $N_{tot.}$ – spectrophotometric method applying UV-VIS Pharo 300 device,
- pH – potentiometry PN-EN ISO 10523:2012,
- total suspended solids (TSS)- gravimetric method PN-EN 872:2007+Ap1:2007

4 Results and discussion

Wastewater from the fruit and vegetable processing plant (Table 2) was characterized – as compared to typical sewage from collecting sewage systems – by many times higher BOD_5 and COD values, and much lower concentration of total nitrogen and phosphorus. The pH fluctuated from 6.20 to 7.67 in treated wastewater after the constructed wetlands with the bio-preparation, while in treated wastewater after a control bed (without the addition of bio-preparation), it was in the range from 6.40 to 7.60 (Table 2). The test results showed a high (average 91%) efficiency of organic substance removal expressed in BOD_5 (Fig. 1) in the wastewater treatment process from the fruit and vegetable industry in the constructed wetlands with dosing bio-preparation and 83% in the deposit without bio-preparation during the campaign period at medium load L_{BOD} = 31.56 g/m^{2}d. Effectiveness of organic substance removal expressed as COD (Fig. 1) in the process of wastewater treatment from the fruit and vegetable industry in the constructed wetlands, at medium load of the deposit, L_{COD} = 49.76 g/m^{2}d was 90% for the bed with dosing bio-preparation and 82% for the bed without addition of bio-preparation. Even higher, 98.5% average efficiency in reducing BOD_5 and COD values were obtained by Paing and Voisin during treatment of municipal wastewater in vertical constructed wetlands with 9 times higher BOD_5 load, 2 times higher COD load, and 7 times higher hydraulic load [32]. Very high, 95% efficiency of organic substance removal expressed in COD was obtained by Koottatep *et al.* in studies conducted for household wastewater [33]. Lower, efficiency in the reduction of organic matter expressed in BOD_5 (89.8%) and COD (64.7%) was received by Dąbrowski in a vertical flow constructed wetlands in the scope of purification of dairy leachates [34]. Results of the research carried out in France upon the transfer of experiments in the field of sewage sludge dewatering showed a decrease in COD value by 93% with over 22 times higher COD load and similar hydraulic load than in own research [35]. The efficiency of removal of total suspended solids (Fig. 1) in the bed with addition of bio-preparation was 76.9%, while on the bed without bio-preparation 57.4% at medium bed load L_{TSS} = 12.56 g/m^{2}d in the campaign period. Higher, 89% efficiency of removing total sediments from sewage sludge in reed beds was obtained by Liénard and Payrastre [36]. In research conducted by Troesch *et al.* in the field of sewage sludge dewatering, higher, average 95% efficiency of removing total suspended solids with 40 times higher load, was achieved [35]. Even higher, 99% efficiency of total suspensions removal was achieved by Kinsley and Crolla [37]. Higher than that obtained in the own research, 90% efficiency of removing the total suspended solids was reached by Kengne et al. conducting tests on sludge dewatering using vertical bed [38]. Effectiveness of total nitrogen removal (Fig. 2) from wastewater from the fruit and vegetable industry in the constructed wetlands with bio-preparation dosing amounted to 36% and 26% in the bed without bio-preparation, at medium load of the deposit L_N = 0.34 g/m^{2}d during the campaign period. Higher, 70,6% efficiency in the reduction of total nitrogen was received by Dąbrowski in a vertical flow constructed wetlands in the scope of purification of dairy leachates [34].The low efficiency of total nitrogen removal in own research results from the fact that sewage from the fruit and vegetable industry is poor in nitrogen and nitrate nitrogen was the dominant form in the outflow from the constructed wetlands. This indicates low intensity of the denitrification process, which in turn indicates good aeration of the deposit. A similar observation was made by Soroko for wastewater from the fruit and vegetable industry [7]. Tanner noted significant effect of the presence of hydrophytes on the amount of the load removed, which could indicate their significant role in the removal of total nitrogen [39]. Effectiveness of total phosphorus removal (Fig. 2) in sewage from the fruit and vegetable industry in constructed wetlands with the bio-preparation was 65% and 38% in the bed without bio-preparation, at medium load of deposit L_P = 0.1 g/m^{2}d. Troesch et al. [35] achieved a 95% efficiency in the removal of total phosphorus on constructed wetlands in the field of sewage dewatering, with the load being 200 times higher than that assumed in own research during the campaign period. High, 98% efficiency of the total phosphorus removal during the treatment of leachate from landfill sites on constructed wetlands was recorded by Kinsley and Crolla and comparable hydraulic load used in own research [37]. According to Brix, Kadlec and Knight, Reddy phosphorus is removed in the constructed wetlands both in abiotic and biotic processes depending on temperature [40–42].

Table 2. Values of parameters in raw sewage from the fruit and vegetable industry supplied to and discharged from the bio-preparation supported constructed wetlands and the deposit without bio-preparation from the campaign period (2015 and 2016).

Parameters	**Unit**	**Raw wastewater***	**Wastewater treated with bio-preparation addition***	**Wastewater treated without bio-preparation addition***
BOD_5	$mgO_2 \cdot dm^{-3}$	3155.00/2500.00/1666.97 1400.00–7200.00	228.00/98.00/255.04 50.00–800.00	419.00/340.00/305.65 50.00–1100.00
COD	$mgO_2 \cdot dm^{-3}$	4975.00/4065.00/2595.00 2595.00–10000.00	368.00/185.00/308.89 160.00–1030.00	653.00/531.00/461.31 187.00–1726.00
TSS	$mg \cdot dm^{-3}$	1257.00/1214.00/96.19 1119.00–1378.00	300.77/210.00/242.43 70.00–870.00	550.00/640.00/304.36 140.00–1090.00
Total nitrogen	$mgN \cdot dm^{-3}$	34.00/30.00/15.98 12.00–75.00	22.00/20.00/11.93 9.00–55.00	24.00/24.00/13.09 10.00–61.00
Total phosphorus	$mgP \cdot dm^{-3}$	2.00/1.20/2.38 0.30–9.50	1.00/0.70/1.72 0.30–6.80	2.00/1.20/2.38 0.30-9.50
pH	-	3.70–6.40	6.20–7.67	6.40–7.60

* arithmetic mean/median/standard deviation of the measurement
min – max

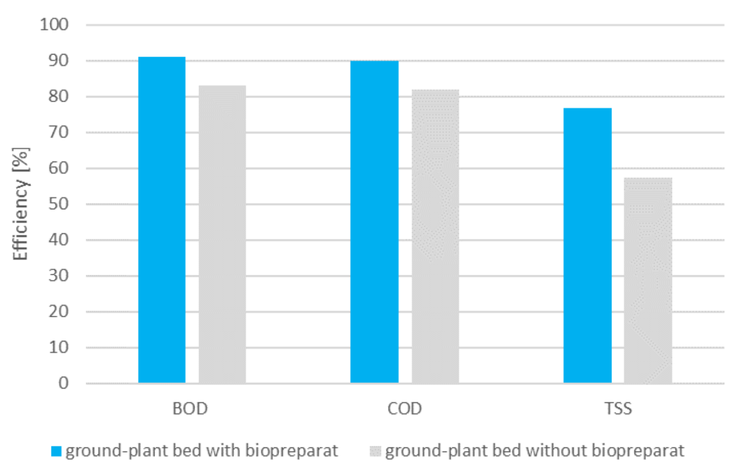

Fig. 1. The efficiency of BOD_5, COD and TSS removal on constructed wetland.

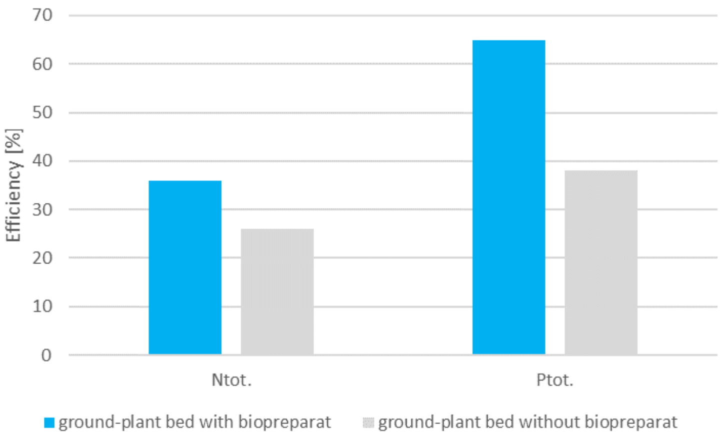

Fig. 2. The efficiency of nitrogen and phosphorus removal on constructed wetland.

5 Conclusions

Analysis of the measurements made allows the following statements:

1. In the case of the analysed parameters, their considerable variability due to the method of production process implementation in the fruit and vegetable processing plant is evident. It is characterized by periods of increased fruit and vegetable juices production (during the campaign period).
2. Raw sewage from fruit and vegetable processing plants is characterized by high values of organic matter expressed as BOD_5 and COD, large amount of total suspension, while low concentrations of nitrogen and phosphorus compounds.
3. Constructed wetlands treatment plant ensures high removal of organic compounds expressed as BOD_5 and COD, as well as guarantees reduction in the concentration of nitrogen and phosphorus compounds.
4. The use of bio-preparation in the constructed wetlands made it possible to increase the effectiveness of wastewater treatment in the campaign period by 8% respectively in the case of organic substances referred to as BOD_5 and COD, total suspended solids by 19.45%, total nitrogen by 10% and total phosphorus by 27% in relation to the deposit without addition of the bio-preparation.
5. Constructed wetlands with vertical flow assisted with bio-preparation purify wastewater from a small fruit and vegetable processing plant with high efficiency.
6. Innovation of the proposed solution consists in the use of bio-preparation prior to introducing into the constructed wetlands during treatment of wastewater from the fruit and vegetable industry.
7. Research upon the use of bio-preparation before introduction into the constructed wetlands in treatment of wastewater from fruit and vegetable processing should be continued with the use of an implementation installation working at a small fruit and vegetable processing plant.

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