Analysis of energy consumption parameters in wheat harvesting using grain harvesters

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Abstract. The paper analyses the energy consumption parameters of three grain harvesters for harvesting wheat. It has been found from the studies that the nominal throughput of the two harvester models K1 and K2 is very close, 7.88 kg/s on average, while for the third harvester K3 it is 9.33 kg/s or 16% higher than the two harvesters. In addition, the direct energy consumption of the observed three harvester models has been established, which averaged 312.57 MJ/t. The consumption of diesel fuel for the harvest of 1 ton of wheat with the harvesters has been determined, and the average consumption was 7.46 kg/t. The average total energy consumption of the three grain harvesters has been determined (1.19 GJ/t), ranging from 1.15 GJ/t to 1.24 GJ/t. From the obtained results, it can be seen that the lowest result has been obtained with harvester K3, since it has the largest working width of the header and the unloading of the grain hopper takes place while moving.

Keywords: grain harvesters, energy consumption, diesel fuel consumption, hopper unloading, operation parameters, energy consumption indicators

Introduction

The harvesting of cereals is one of the critical processes in agriculture. A huge amount of work needs to be done within a short period of time. In order to deliver high productivity with minimal crop losses, damage and minimal expenses on maintenance, the combine harvester needs to be a high-tech one (Dumitru et al., 2020). The main technological operations that are carried out simultaneously during crop harvesting are: harvesting, threshing, separation, cleaning of the grain and temporary storage and unloading of the grain (Nikolov et al., 1974; Georgiev and Staniev, 1988; Genov et al., 2008; Ishpekov, 2013). Harvesting the grain from the point of view of work organization is a process of simultaneous work of people, harvesters and transportation vehicles. Other machines, such as tractors with ploughs and water tankers, also support this process. Cereal crops must be harvested within a relatively short period of time to avoid production losses caused by the extended harvest period (Delchev and Trendafilov, 2015; Trendafilov and Dragoev, 2019). These losses, as a rule, are the greatest during unfavourable weather conditions (Trendafilov and Dragoev, 2017).

It has been found that harvesting some agricultural crops consumes from 26% to 42% of the total labor consumption for their cultivation. This requires high degree of organization of the harvesting equipment and its maintenance in a workable technical condition in order to harvest all crops within the optimal agrotechnical time (Kolev, 1999). According to Vasilievich (2011), this process is of great importance, since the final results of the whole year's work are collected. Other authors have theoretically compared the consumptions of two technologies for threshing cereals – stationary technology and direct harvesting (Bulgakov et al., 2010). Their calculations indicate that it can be seen that the technology with stationary threshing and separation of cereal crops is 2.8 times cheaper than direct harvesting.

Harvesting costs constitute about 30% of total costs. That is why the optimum organization of work and use of machinery are the significant components for cost reduction and increasing the productivity of grain harvesters (Sørensen, 2003).

Some authors assess the effect of weather conditions on the costs for cereal harvesting (Alfredo et al., 2012). According to other authors, efficiency in crop harvesting can be considerably improved by creating optimum models for harvest, which will minimize idle time (Bochts et al., 2007).

Models have been developed to predict the performance of cereal harvesting taking into account the conditions of the agricultural enterprise. Through the created computer software, it is possible to analyze the efficiency of use of grain harvesters (Erokhin and Reshetov, 2010). Lezhentzkin (2007) has considered the issue of energy consumption during harvesting, and its reduction has been identified as a primary objective task. Struzhkin mainly focuses on issues of improving harvester efficiency. He developed an economic-mathematical model for determining the technological and technical parameters of the machines, and the confirmed optimization calculations confirmed the production system: field-harvester-transport-grain storage (Struzhkin, 2008 a, b).

The quality of work of grain harvesters, as well as other harvesting machinery, and their ability to work at maximum productivity with a suitable mode under different conditions depend not only on the load, but also on their energy capacity (Georgiev and Staniev, 1989). The distribution of power in self-propelled grain harvesters depends on the way of transmitting the energy for its movement and for driving its working organs (Georgiev and Staniev, 1989; Beloev et al., 2018).

Objective of this study is to conduct a comparative analysis of the energy consumption of three models of grain harvester during the harvest campaign for wheat harvesting.

Material and methods

The object of study are three grain harvesters of the same brand, and their models have been replaced by the conventional designations K1, K2 and K3. With the first two harvesters K1 and K2, Renaissance variety of wheat has been harvested at an average yield of 6.6 t/ha, while the average moisture recorded by the on-board moisture meter of harvester K1 was 12.4% and that of harvester K2 was 12.2%. The unloading of their grain hopper took place in stopped position. The two grain harvesters had the following technical parameters: working width of the headers 6.6 m, the volume of their grain hoppers 8.6 m3 and the discharge auger flow rate was 100 l/s.

With the third grain harvester K3, wheat was also harvested, from the Sobel variety, the average yield being 5.2 t/ha, while the average moisture recorded by the on-board moisture meter of the harvester – 11.9%. The unloading of the grain hopper of the K3 harvester was carried out on the move.

The research was conducted during the wheat harvest campaign. It was carried out separately in two blocks as follows: on block A (Figure 1) when harvesting the Sobel variety at an area of 27.6 ha, and the actual grain yield per decare was 5.2 t/ha and on block B (Figure 2) when harvesting the Renaissance variety at an area of 92 ha, and the actual grain yield per hectare was 6.6 t/ha.

The studies have been conducted under real production conditions without changing and affecting the harvesting organization created.
Defining some basic operation parameters characterizing the work of grain harvesters is made by the correlations (Ishpekov, 2013):

The feeding rate of the grain is determined by the formula:
\[ \dot{Q} = m \cdot \eta \cdot \text{kg/s} \]  \hspace{1cm} (1)

Where \( m \) is grain weight in the harvester hopper, kg. (Defined on the basis of the weighing machine notes on the farm); \( \eta \) – time for which the harvester grain hopper is filled, s. (Defined by chronomerting from beginning of harvest till the harvester stops harvesting after the hopper is 100% full).

The nominal throughput \( q_n \) is the denoted feeding in which grain losses from the thrasher are up to 1.5%, and grain purity in the harvester’s hopper is over 97%. It was defined by the correlation:
\[ q_n = \frac{\dot{Q}_{\text{nom}}}{\eta} = 1.67 \cdot \dot{Q}_{\text{nom}} \cdot \text{kg/s} \]  \hspace{1cm} (2)

Where \( \dot{Q}_{\text{nom}} \) is the flow rate (the feeding) of straw and chaff, kg/s. It is defined by the expression:
\[ \dot{Q}_{\text{nom}} = \frac{Q_{\text{nom}} \cdot \beta}{1 - \beta} \cdot \text{kg/s} \]  \hspace{1cm} (3)

Where \( \beta \) is straw ratio \( \beta = 0.4 \pm 0.8 \). Grain harvesters are assessed at straw ratio \( \beta = 0.8 \). This value of the coefficient corresponds to a mix of 40% grain, 65% straw, and chaff. Due to that reason for our harvest conditions straw ratio \( \beta = 0.6 \) is adopted.

Defining total energy consumption for harvesting one ton of grain was made by the correlations:

Defining energy needed for harvesting one ton of grain \( E \) is described by the sum total (Ishpekov, 2013):
\[ E = E_{\text{op}} + E_{\text{ch}} + E_{\text{f}} \cdot \text{MJ} \]  \hspace{1cm} (4)

Where \( E_{\text{op}} \) is energy consumption for the operation process, MJ/t; \( \eta \) – consumption incurred by the grain harvester operators, MJ/t; \( E_{\text{f}} \) - energy consumption for the production and servicing of the grain harvester, MJ/t.

Energy consumption for the operation process \( E_{\text{op}} \) is described by the sum:
\[ E_{\text{op}} = E_{\text{op}} + E_{\text{ch}} + E_{\text{f}} \cdot \text{MJ} \]  \hspace{1cm} (5)

Where \( E_{\text{op}} \) is energy for the grain harvester movement, MJ/t; \( E_{\text{ch}} \) – energy for idle movement of the grain harvester operating bodies, MJ/t; \( E_{\text{f}} \) – energy for the grain harvester technological processes, MJ/t.

The energy for grain harvester movement \( E_{\text{f}} \) depending on the harvester conditions is defined by the expression:
\[ E_{\text{f}} = 10^{-3} \cdot f \cdot g \cdot (m + m_1) \cdot (1 + k_2) \cdot \eta \cdot \eta \cdot (1 - \delta) \cdot B \cdot D \cdot t \cdot \text{MJ/t} \]  \hspace{1cm} (6)

Where \( f \) is self-movement coefficient, arbitrarily adopted \( f = 0.15 \); \( g \) – gravity, m/s²; \( m \) – grain harvester mass, kg; \( m_1 \) – grain mass in the grain harvester hopper, kg. (Determined on the basis of the weighing machine notes on the farm); \( \eta \) – coefficient of the share of the harvester non-productive moves \( \eta = 0.04 \pm 0.60 \) at work plot length 800 m, arbitrarily adopted \( \eta = 0.1 \); \( \eta \) – effective engine efficiency (for diesel engines), arbitrarily adopted \( \eta = 0.34 \); \( \eta \) – mechanical transmission efficiency (for hydromechanical transmission), arbitrarily adopted \( \eta = 0.68 \); \( \delta \) – grain harvester skidding, arbitrarily adopted \( \delta = 0.035 \); \( B \) – operating width of the grain harvester header, m; \( D \) – grain yield, t/ha.

Energy consumption for the grain harvester technological processes is determined by the expression:
\[ E_{\text{ch}} = 3.6 \cdot q_n \left( \frac{\overline{e}_{\text{ch}}}{\eta_{\text{ch}}} + \frac{\overline{e}_{\text{ch}}}{\eta_2} \right) \cdot \text{MJ/t} \]  \hspace{1cm} (7)

Where \( q_n \) is nominal throughput of the harvester, kg/s, Determined by the formulas (2) and (3); \( \overline{e}_{\text{ch}} \) – specific idle power; \( \eta_{\text{ch}} \) – specific power to carry out technological processes per unit of throughput; \( \eta_2 \) – effective engine efficiency (for diesel engines), arbitrarily adopted \( \eta = 0.52 \); \( \eta_2 \) – grain flow rate (feeding), kg/s. Determined by formula (1).

For modern grain harvesters \( \overline{e}_{\text{ch}} = 2.7 \pm 2.8kW_s / \text{kg} \).

For grain harvesters with single drum thrasher \( \overline{e}_{\text{ch}} = 5.8 \pm 7.3kW_s / \text{kg} \).

For harvesters with double drum thrasher the specific power is 15 \pm 17% greater.

For the studied three models of grain harvesters, since they are with single drum tangential thrasher it is arbitrarily adopted \( \overline{e}_{\text{ch}} = 2.7 \) and \( \overline{e}_{\text{ch}} = 7.1kW_s / \text{kg} \).

Energy consumption for grain harvester operators \( E_{\text{op}} \)

The energy consumption for grain harvester operators is calculated with the expression:
\[ E_{\text{op}} = \frac{W_{\text{ch}} \cdot N_{\text{op}}}{Q_{\text{ch}}} \cdot \text{MJ/t} \]  \hspace{1cm} (8)

Where \( W_{\text{ch}} \) is the energy equivalent of the harvester operator work according to the rates of FAO \( W_{\text{ch}} = 1.26 \text{MJ/h} \cdot \text{h} \); \( N_{\text{op}} \) – number of harvester operators. Each harvester is operated by one harvester operator. \( \tau \) – coefficient of utilization of the shift work hours. It has been arbitrarily adopted \( \tau = 0.8 \).

Energy consumption for production, repair and servicing the grain harvester \( E_{\text{f}} \)

The energy consumption for production, repair and servicing the grain harvester is determined by the expression:
\[ E_{\text{f}} = \frac{W_F \cdot (A_O + A_{O_{\text{in}}})}{Q_{\text{f}}} \cdot \text{MJ/t} \]  \hspace{1cm} (9)

Where \( W_F \) is the energy consumption for production and technical servicing of the grain harvesters, MJ/t; \( \eta_{\text{f}} \) – energy efficiencies for equivalent energy consumption for production of 1 kg of the grain harvester mass \( W_F = \frac{W_{\text{ch}}}{A_O + A_{O_{\text{in}}}} = 120 \text{MJ} \) for self-propelled grain harvesters; \( t \) – construction grain harvester mass, t; \( A_O \) and \( A_{O_{\text{in}}} \) – depreciation deductions for production and for major repairs. It has been arbitrarily adopted \( A_O = 0.111 \) and \( A_{O_{\text{in}}} = 0.104 \); \( \tau \) – the amount of hours for annual work load, h.

The diesel fuel consumption for harvesting 1 ton of wheat by the three models of grain harvesters is defined by the following expression:
\[ \Gamma = \frac{Q_{\text{ch}}}{W_{\text{ch}}} \cdot \text{kg} \]  \hspace{1cm} (10)

Where \( Q_{\text{ch}} \) are the direct energy costs of the grain harvesters, MJ/t; \( W_{\text{ch}} \) – the energy content of the diesel fuel, MJ/kg.

Results and discussion

Table 1 presents the operational indicators of grain harvesters. It also contains the results about the calculated flow rate (feeding) of grain, the flow rate (feeding) of straw and chaff, the measured average time for hopper filling and the actual load of the wheat mass in the harvester grain hopper. The last column in the table contains the nominal throughput of the three grain harvesters.

It is evident from the table that the nominal throughput of both harvesters K1 and K2 is very close 7.88 kg/s on average, while for the third harvester K3 it is 9.33 kg/s or 16% more than the two harvesters. One of the underlying causes is the operation width of their headers, since both harvesters (K1 and K2) have the same operation width of 6.60 m, while the third one (K3) has operation width 7.50 m, i.e. 90 cm more than the first two.

| Table 1. Basic operational indicators characterizing the grain harvester operation |
|---------------------------------|----------------|----------------|----------------|----------------|----------------|
| Indicators                      | Average time for hopper filling t | Grain mass in the hopper m | Flow rate (feeding) the grain \( g \) | Feeding straw and chaff \( Q_{\text{ch}} \) | Nominal throughput \( q_n \) |
| Grain harvester                | 1786           | 5871           | 3.12           | 4.68           | 7.82           |
| K2                              | 1740           | 5529           | 3.17           | 4.76           | 7.94           |
| K3                              | 1908           | 7114           | 3.73           | 5.59           | 9.33           |

It is evident from Table 1 that the weighing machine notes show that the transportation vehicles in all three grain harvester models transported an average of 587 kg to 7114 kg of wheat at each trip at wheat volume weight of 720 kg/m³. Figure 3 shows the actual volume of the grain hopper filled by each harvester.
It is evident from Figure 4 that diesel consumption for harvesting 1 ton of wheat is 7.46 kg/t on average for the three harvesters and varies from 7.16 kg/t to 7.4 kg/t. It is evident that it is the lowest in the third harvester model (K3) - 7.16 kg/t. This could be attributed to the harvester's ability to unload the grain hopper while in motion, resulting in a shorter overall harvesting time. Additionally, this harvester model has a header that is 90 cm wider, measuring 7.5 m compared to the 6.60 m of K1 and K2.

Table 3 presents the results about energy consumption by the harvester operators, the energy consumption for production and for technical servicing of the harvesters.

Table 3. Energy consumption by the harvester operators, for production and for technical servicing of the grain harvesters

<table>
<thead>
<tr>
<th>Grain harvester</th>
<th>$E_a$ (MJ/h)</th>
<th>$E_a$ (MJ/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>0.51</td>
<td>671.87</td>
</tr>
<tr>
<td>K2</td>
<td>0.49</td>
<td>717.24</td>
</tr>
<tr>
<td>K3</td>
<td>0.42</td>
<td>653.65</td>
</tr>
</tbody>
</table>

It is evident from Table 3 that energy consumption by harvester operators varies from 0.42 MJ/hm to 0.51 MJ/hm. It can be seen that with the K3 harvester it is 18% lower, since the grain feed is the largest in it - 3.73 kg/s.

Energy consumption for the production and for technical servicing of the grain harvesters is detailed in the second column of Table 3. It is evident from it that the average consumption is 680.92 MJ/t and varies from 653.65 MJ/t to 717.24 MJ/t. It is evident from these results that it is the highest in the second harvester model K2 – $E_a = 717.24$ MJ/t. One reason for this was that the harvester frequently stopped due to issues encountered within the field.

Table 4 presents the total energy costs of grain harvesters.

Table 4. Total energy costs of grain harvesters

<table>
<thead>
<tr>
<th>Grain harvester</th>
<th>$Q_*$ (t)</th>
<th>$E_a$ (MJ)</th>
<th>$E_a$ (MJ)</th>
<th>$E_a$ (MJ)</th>
<th>E (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>315.84</td>
<td>0.51</td>
<td>886.26</td>
<td>1.18</td>
<td></td>
</tr>
<tr>
<td>K2</td>
<td>316</td>
<td>0.49</td>
<td>924.74</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>K3</td>
<td>305.88</td>
<td>0.42</td>
<td>842.76</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>

It is evident from Table 4 that these are 1.19 GJ/t on average, varying from 1.15 GJ/t to 1.24 GJ/t. It is obvious that the lowest result is obtained for the third harvester model K3, since it has the greatest working width of the header and the grain hopper is unloaded while moving.

Conclusion

The following has been established: (i) the nominal throughput of grain harvesters. For the two models K1 and K2 it is very close, an average of 7.88 kg/s, while for the third K3 it is 9.33 kg/s or 16% higher than the two harvesters. The reason is the working width of their headers, since in the two harvesters they were with the same working width of 6.60 m, while the third one had working width of 7.50 m. (ii) Direct energy costs in the studied harvester models – 312.57 MJ/t, and in the three grain harvester models they vary from 305.88 MJ/t to 316 MJ/t. (iii) The diesel consumption for harvesting 1 ton of wheat varies among the three grain harvester models. The average consumption is 7.46 kg/t and varies from 7.16 kg/t to 7.4 kg/t. The lower fuel consumption in model K3 – 7.16 kg/t is due to the mode of its unloading – unloading while moving. In addition, the working width of the header is 90 cm bigger. (iv) Energy consumption by the harvester operators, varying from 0.42 MJ/hm to 0.51 MJ/hm. It is evident that in harvester K3 it is 18% lower, since in it the flow rate is the biggest 3.73 kg/s. (v) The average total energy costs of the three grain harvesters 1.19 GJ/t, varying from 1.15 GJ/t to 1.24 GJ/t. It is evident that the lowest result is obtained for harvester K3, since it has the greatest working width of the header and the grain hopper is unloaded while moving.
Influence of the extraction method on phytochemicals content and antioxidant activity of *Sambucus nigra* flowers

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Abstract. *Sambucus nigra* L. (elder) is one of the most common plant species in Europe, widely used for its health and healing properties and with a long botanical history. In the present study, elderberry flowers were subjected to different extraction methods (infusion, decoction, microwave- and ultrasound- assisted extraction) and their phytochemical content and antioxidant potential were evaluated. As a result, the total phenolic content in the extracts varied between 34.21 ± 0.42 and 47.46 ± 1.87 mg GAE/g dw and the total flavonoid content was found to be in the range of 11.69 ± 0.16 and 16.18 ± 0.23 mg QE/g dw. The highest values were reported for decoction. Organic acid, phenolic acid and sugar profiles of content were evaluated and compared. Extraction method had a profound effect on the content of sugars, phenolic and organic acids extractability from the plant matter, decoction being the most efficient extraction method. In addition, the correlation between the analyses was studied, outlining the contribution of the contained phytochemicals. In conclusion, aqueous extracts of elderflowers can be considered a promising source of natural antioxidants and should be further investigated for the specific profile of phytochemicals present and promoted for consumption.

Keywords: antioxidant activity, phenolic and flavonoid content, elder flowers, green extraction, phytochemicals

Introduction

The consumption of plants dates back to ancient times. People use plants for different aspects – food, medicine, building materials, clothing, furniture, shelter, pollution control, etc. Without a doubt, one globally significant use is to enhance human wellbeing through food additives. One of the most important and worldwide distributed aspect of use is for improvement of the wellbeing of people as a food additive. Furthermore, the World Health Organization (WHO) strategy, 2014–2023, aims to strengthen the role of traditional medicine, emphasizing the importance of promoting and integrating the use of medicinal plants in the health systems of Member Countries (WHO, 2013).

Recently, the flowers of *Sambucus nigra* L. (elder) have garnered increased attention. Sambucus flowers are used to flavor wine and to make tea and nonalcoholic cordial (Charlebois et al., 2010). Among the various parts of *S. nigra*, only the flowers and fruits are considered medicinal. Specifically, elder flowers are approved by the German commission E for colds (Blumenthal et al., 2000). Meanwhile, fruits, leaves and bark are not approved by the WHO, ESCOP and the German Commission E (Ulbricht et al., 2014) possibly due to the potentially toxic cyanogenic

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