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Model-based Assessment of Manual Raspberry Harvesting Efficiency Using the CIOSTA Methodology in Tunnel-Grown Production Systems

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ABSTRACT

The aim of this study was to assess how raspberry cultivar and work organization influence the efficiency of manual harvesting under intensive tunnel-grown production. The research was carried out in July and August 2022 on a 20-hectare plantation and included four cultivars: Kwanza, Malling Bella, Enrosadira, and Diamond Jubilee.

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ABSTRACT

The CIOSTA methodology was applied, combining detailed time measurements and full-day work observations, which enabled an in-depth analysis of effective time, auxiliary time, transport time, and work losses. In July, the average total harvest time was 240.7 rbh·ha⁻¹, while in August it decreased to 153.2 rbh·ha⁻¹. The highest efficiency was recorded for the Diamond Jubilee cultivar (K_{07} = 0.82), whereas the lowest values were observed for Malling Bella in July and Enrosadira in August. Transport-related activities accounted for the largest share of time losses, which is reflected in the transport utilization coefficient K_t (0.43-0.44). The results indicate that harvest efficiency depends not only on the cultivar and its yield potential but also on work organization and internal logistics. The findings confirm that the structure of the harvesting proces-particularly transport Logistics-plays a key role in determining overall efficiency. The presented analysis provides valuable input data for developing simulation and optimization models that support the design of improved work organization solutions in horticultural farms. The study aligns with current research trends in organizational and logistical analysis within horticultural production and forms a basis for creating model approaches to soft-fruit harvesting systems.

Introduction

The market and consumption of berry fruits have shown a steady upward trend in recent years. According to statistical data, in 2023 the leading global producers of raspberries were Russia (220 thousand tons), followed by Mexico (190 thousand tons) and Serbia (99 thousand tons). Poland ranked fifth worldwide and remained one of the top raspberry producers in Europe, with a production volume of 115,870 tons, making it one of the largest producers on the continent (Report Linker, 2023, online). Poland is therefore considered a significant raspberry-producing country globally. According to data from the Central Statistical Office (GUS), the raspberry cultivation area in Poland in 2023 totaled 21.38 thousand hectares, with an average yield of 4.5 t·ha⁻¹. The largest production was recorded in the Lublin region, where raspberry cultivation covered 15.45 thousand hectares with an average yield of 4.7 t·ha⁻¹ (GUS, 2023). It should be emphasized, however, that raspberry-growing areas in Poland are highly dispersed (Wróblewska et al., 2019). The value of the global fresh berry market, including raspberries, is estimated at USD 26.56 billion in 2024 and is expected to reach USD 31.86 billion by 2029 (Industry Reports, 2024).

In 2020, Poland accounted for 51% of raspberry production in the European Union, ahead of Spain (22%) and Portugal (12%). Raspberries are the third most widely produced berry fruit in Poland, after strawberries and currants. Their share in the overall berry harvest is approximately 25%. In recent years, the raspberry cultivation area has shown only slight fluctuations, ranging from 28 to 30 thousand hectares (KOWS Report, 2021, online; Eurostat, 2020, online). According to data from Statistics Poland (GUS), annual raspberry yields in Poland varied between 76-78 thousand tons in the poor harvest years of 2015 and 2019, and up to 129 thousand tons in 2016. In 2020, nearly 116 thousand tons were harvested (KOWS Report, 2021, online).

Raspberries are considered relatively difficult crops to grow. Achieving high yields of good quality requires substantial investment in foil tunnels and irrigation systems, as well as the use of cultivars characterized by desirable flavor traits, high productivity, and disease resistance. Between 2012 and 2020, average raspberry yields in Poland ranged from 2.6 to 4.5 $t \cdot ha^{-1}$ (KOWS Report, 2021, online). Raspberries are available on the market in fresh, frozen, and processed forms (such as concentrates, juices, syrups, jams, compotes, and liqueurs) (Bulatović, 2020).

Depending on the cultivar, raspberry fruit color may vary from light red to dark red, purple, black, yellow, or even white (Danek, 2014). Due to their sensory qualities and health benefits, red raspberries (*Rubus idaeus* L. subsp. idaeus) are the most popular among consumers (Baldassi et al., 2024). Red raspberries are rich in vitamins, folic acid, anthocyanins, ellagitannins, and mineral elements. They also contain simple sugars, organic acids, pectin, mucilaginous compounds, and other phytochemicals. Scientific studies confirm the preventive effects of bioactive compounds found in raspberries against many lifestyle-related diseases (Krauze-Baranowska et al., 2014; Bobinaitė et al., 2016; Kim et al., 2016).

The profitability and competitiveness of raspberry production depend on numerous economic and climatic factors, as well as individual decisions made by growers (Paszko, 2008). Raspberry plants are challenging to cultivate. Due to their shallow root system (most roots occur in the top 0-25 cm of soil), the shrubs are particularly sensitive to both excess and shortage of soil moisture. Even short periods of drought can strongly and negatively affect plant growth and fruiting (Danek, 2014).

Currently, in large-scale professional cultivation, raspberries are grown in tunnels covered with UV foil. The plants fruit in containers placed on compacted soil covered with agrofabric to prevent weed growth. Due to their high productivity, long-cane plants are commonly used. These long-cane plants develop shoots ranging from 1.5 to about 2.2 meters, which means they require carefully controlled conditions on the plantation. Typically, the plants grow in 7-liter containers filled with a suitable growing medium, selected individually by each farm. While soil cultivation is also possible, container cultivation offers better control over environmental parameters. Research shows that plants grown in containers have greater yield potential and produce larger fruit compared to those grown in the ground (Mielczarek, 2009; Sokolowski & Banks, 2010). Moreover, containers are easier to prepare and store in cold rooms during winter.

The harvesting of soft fruits, including raspberries, is one of the most labor-intensive stages of horticultural production and has long been the subject of studies on work organization, ergonomics, and production process modeling. Despite advancements in mechanization in other areas of crop production, manual harvesting remains the dominant method for collecting dessert-quality fruit, mainly due to the need to maintain high commercial quality (Mielczarek, 2009). For example, in Hungary, a shortage of labor for manual raspberry harvesting contributed to a decline in production, regardless of cost conditions (Apáti, 2014). Due to persistent labor shortages faced by berry growers, mechanizing the harvest - especially on large plantations - has become a necessity. This would shorten working time, reduce the number of employees required, increase productivity, and lower production costs. According to Marković et al. (2017), mechanical raspberry harvesting is 3-4 times cheaper than manual harvesting. However, the quality of mechanically harvested fruit is somewhat lower compared to fruit picked by hand, although it remains suitable for processing (Mika et al., 2016).

The literature emphasizes that classical approaches to work organization can be enhanced with modeling and simulation methods, which help better reflect the complexity of processes under variable agricultural conditions (Mielczarek, 2009). Simulation modeling is used, among other applications, in the analysis of logistics systems and transport processes in horticultural operations (Matuszek, 2016). In this context, working time and the structure of harvesting activities can be viewed as elements of a logistics system in which material flow (fruit), human resources, and internal transport organization play key roles.

Research on optimizing harvesting processes increasingly uses a systems approach that incorporates various organizational scenarios and evaluates their influence on overall efficiency. Sokolowski & Banks (2010) note that discrete-event simulations are especially useful for analyzing short, repetitive processes - precisely the nature of soft fruit harvesting. In studies on logistics process management (Matuszek, 2016), authors highlight the potential of optimization tools for determining appropriate staffing levels, organizing work crews, and reducing time losses associated with auxiliary and transport activities.

The soft fruit harvest process (e.g., raspberries) is characterized by a high share of labor costs - about 40% of total production expenses - which makes it an economically important target for improvements in work organization (Simnitt & Martin, 2022; Win, 2025). Previous studies (Malaga-Toboła et al., 2013; Kwaśniewski et al., 2013; Góral & Rembisz, 2018; Kuboń, 2018; Marzec et al., 2019) show that it is essential not only to monitor effective harvesting time but also to analyze time losses and their sources, such as internal transport, handling activities, and technological breaks.
The literature highlights that such processes can be effectively modeled and optimized using advanced tools such as linear, integer, and stochastic programming, often supported by simulation. These methods are applied in harvest planning and production management (Sokolowski & Banks, 2010; Matuszek, 2016; Tüskıner & Bilgen, 2021; Nguyen, 2021).

The inability to mechanize raspberry harvesting on the plantation means that manual harvesting costs represent the dominant share of overall production expenses. The developed modeling approaches can help reduce labor requirements, lower the cost intensity of harvesting, and consequently improve the economic efficiency of producing fresh market raspberries.

The research undertaken on the efficiency of raspberry harvesting using time studies and full-day work observations is justified from both practical and scientific perspectives. In real production conditions, rising seasonal labor costs, limited labor availability, and increasing quality requirements from the market create a need to optimize harvest organization.

Applying the CIOSTA methodology, which includes a detailed classification of working time, makes it possible to accurately determine the share of productive and non-productive activities. The introduction of the operational time utilization coefficient (K_{07}) and the working time utilization coefficient (K_{02}) enables a quantitative assessment of organizational efficiency and allows for their comparison across cultivars and harvesting periods. In the context of production process modeling, the collected data can be used to: develop simulation models reflecting various harvest organization scenarios, optimize the number of workers and the structure of work teams, identify major sources of time losses and propose improvement actions (e.g., reducing internal transport time), design innovative organizational solutions that increase harvest efficiency and reduce unit costs.

Thus, this research represents an important step toward developing model-based organizational solutions for berry harvesting, which may support further work in computer simulation and process optimization. The study fits within broader research efforts focused on improving harvest efficiency and agricultural logistics, linking traditional work-study tools with modern system modeling methods.

The aim of the study was to assess the impact of raspberry cultivar and work organization on the efficiency of manual raspberry harvesting, with particular emphasis on the seasonal employment of workers. Manual harvesting requires an appropriate work organization system based on determining individual labor inputs associated with the number of employees involved in the harvest. The number of workers and their productivity significantly affect the total labor inputs expressed in working hours (rbh). The efficiency of raspberry harvesting was evaluated using the harvest time efficiency coefficient and the working time utilization coefficient.

Material and methods

The scope of the study included detailed field research conducted on a raspberry plantation using work-time chronometry. This approach made it possible to characterize the harvesting process, determine the share of each activity in the overall working time structure, and identify areas or activities where labor inputs could be reduced. This is crucial for optimizing the organization of the harvesting process. The research involved performing time measurements for selected cultivars and raspberry production sectors, as well as determining both unit and total labor inputs.

Field research was carried out on a raspberry plantation in the village of Sławoszynko near Karwia, in the Pomeranian Voivodeship. The studies described above were conducted in July and August 2022, that is, at the beginning of the raspberry harvest season and at its peak. The input data were collected using specially prepared research questionnaires and then subjected to quantitative, qualitative, and statistical analysis. The criteria for selecting raspberry cultivars included the cultivar type, the cultivated area within the tunnel, the type of substrate used as the growing medium, and the number of plants in each production section. Four cultivars were selected for the study: Kwanza, Enrosadira, Malling Bella, and Diamond Jubilee.

The efficiency of labor inputs and work performance during manual raspberry harvesting depends primarily on the proper organization of the harvest. This is due to the strict dependence of the harvest schedule on agrotechnical timing, as the rational use of working time influences both the timeliness of individual tasks and overall harvesting efficiency.

In the context of the study on determining raspberry harvesting time, two concepts are essential:

- chronometry – the observation and measurement of the duration of short, repetitive activities,
- workday photography – the observation and measurement of all elements of working time throughout the entire observation period.

To analyze human working time in the production process, mainly to improve work organization, measurements of the duration of individual activities are carried out. The assessment uses a time classification system developed by the International Center for Scientific Organization of Work in Agriculture (CIOSTA).

Table 1 presents the working time classification developed for manual raspberry harvesting. This classification was used to conduct working-time chronometry on the raspberry plantation and to perform workday photography for workers performing manual harvesting.

The basic category of time is the effective working time T_1, during which the worker manually picks raspberries from the bushes and places them into previously prepared containers and crates. Only during this period does the worker perform actual (effective) work. All other activities represent justified or unjustified time losses that negatively affect overall work efficiency and the total duration of the raspberry harvest.

During manual raspberry harvesting, auxiliary time T_2 plays an important role, as it is directly linked to the main working time. It includes the time spent collecting the cart, containers, and crates at the beginning of the day (T_{21}), the time spent waiting in line to weigh the harvested raspberries (T_{22}), and the time at the end of the workday needed to return the cart and empty crates or containers to their designated place (T_{23}).

The sum of effective time T_1, auxiliary time T_2, and transport time T_3 constitutes the working time T_{02}, which has a decisive influence on productivity and, consequently, on the overall duration of the harvest. The total harvest time T_{07} is defined as the sum of effective manual harvesting time T_1 and all time losses T_{01} arising from reasons dependent and independent of the workers during the harvesting process. To assess the efficiency of manual raspberry harvesting, the following coefficients were used according to the adopted calculation methodology:

- the effective harvest time utilization coefficient K_{07} (-),
- the working time utilization coefficient K_{02} (-).

Additionally, to evaluate time losses T_{01}, the following coefficients were determined:

- the transport time utilization coefficient K_t (-),
- the handling activities utilization coefficient K_{cm} (-).

In calculating the K_{02} and K_{07} coefficients, the total harvest time T_{07}, the effective harvest time T_1, and the working harvest time T_{02} were taken into account. The working time T_{02} consists of the following components: effective harvest time T_1, auxiliary time T_2, and transport time T_3. In turn, when calculating the K_t and Kcm coefficients, the transport time T_3, the handling time T_4, and the total time losses T_{01} were considered.

Based on the structure of both unit and total times, efficiency coefficients for manual raspberry harvesting were calculated using detailed time-study measurements taken during the harvest. The study defined the following:

- the effective harvest time utilization coefficient (K_{07}), calculated as the ratio of effective time to the total harvest time:

$$K_{07} = \frac{T_1}{T_{07}} \tag{1}$$

- the working time utilization coefficient (K_{02}), calculated as the ratio of effective time to working time:

$$K_{02} = \frac{T_1}{T_{02}} \tag{2}$$

Tabela 1

Classification of working time in manual raspberry harvesting

	T_1		**effective raspberry picking time** time during which the worker manually picks raspberries from the bushes and places them into previously prepared containers and crates	
	T_2		**auxiliary time**	$T_2 = T_{21} + T_{22} + T_{23}$
		T_{21}	**time for collecting the trolley, containers, and crates** time needed at the beginning of the workday to perform these activities	
		T_{22}	**waiting time in the queue for weighing** time spent waiting in line to weigh the collected raspberries	
		T_{23}	**time for returning the trolley, containers, and crates after harvesting** time needed at the end of the workday to perform these activities	
	T_3		**transport time**	$T_3 = T_{31} + T_{32} + T_{33}$
		T_{31}	**travel time from the collection point to the field rows** time spent travelling from the place where containers are collected to the rows where harvesting will occur	
		T_{32}	**travel time with full containers to the weighing area** time spent travelling from the point where crates are filled to the weighing station	
		T_{33}	**empty" travel time from the weighing area back to the harvesting site** time spent travelling from the weighing station back to the harvesting area	
T_{02}			**WORKING TIME**	$T_{02} = T_1 + T_2 + T_3$
	T_4		**handling time**	$T_4 = T_{41} + T_{42} + T_{43}$
		T_{41}	**time for rearranging crates with containers** time spent rearranging crates during harvesting and weighing procedures	
		T_{42}	**time for weighing the harvested raspberries** time needed to weigh raspberries in crates and containers	
		T_{43}	**time allocated for sorting raspberries** time required for additional sorting of raspberries after harvesting	
	T_5		**rest time (break)** time allocated for breaks during the workday	
T_{01}			**WORKING TIME LOSSES**	$T_{01} = T_2 + T_3 + T_4 + T_5$
T_{07}			**RASPBERRY HARVESTING TIME**	$T_{07} = T_1 + T_2 + T_3 + T_4 + T_5$

Additionally, the following coefficients were determined for assessing the use of transport time and handling activities:

– the transport time utilization coefficient (K_t), calculated as the ratio of transport time to the total time losses:

$$K_t = \frac{T_3}{T_{01}} \tag{3}$$

– the handling time utilization coefficient (K_{cm}), calculated as the ratio of handling time to the total time losses:

$$K_{cm} = \frac{T_4}{T_{01}} \tag{4}$$

For the raspberry harvesting process to run efficiently, it is essential to maintain a high level of total harvest time utilization, measured as the share of effective harvesting time in the total harvest time (K_{07}). This can only be achieved when time losses T_{01} are minimized, including auxiliary time, transport time T_3, and time spent on handling activities T_4.

The share of effective time is influenced primarily by the conditions under which each activity is performed during the harvest. These conditions were determined mainly by the harvest period (e.g., July, August), the yield of raspberries collected in different sections of the same cultivar, or in different sections and cultivars (e.g., Kwanza, Malling Bella, Enrosadira, Diamond Jubilee).

Subject of research

On the analyzed plantation, raspberry cultivation was carried out in connected tunnels covering an area of 20 hectares. Thanks to the appropriate size of the structures and the use of foil with light-diffusing properties, a favorable microclimate for plant growth is maintained inside the tunnels even during summer heatwaves. The raspberries are grown in containers. Two types of plastic pots are used as growing containers – 7.5-liter and 10-liter ones, either rectangular or oval in shape. Figure 1 shows the raspberry plantation in one of the analyzed tunnels (May 2022).

Figure 1. View of the raspberry plantation and close-up of the raspberry containers

The containers have special legs that prevent the plant root system from coming into contact with the tunnel floor and protect it from being flooded by excess nutrient solution. The pots are filled with coconut substrate designed for raspberry cultivation, supplied by the companies Ceres and Legro.

The plants receive water and nutrients through a fully automated fertigation system. Each pot contains three drip emitters to ensure uniform moisture throughout the entire volume of the substrate. Nutrient delivery is automated, and both the start time of irrigation and the duration of irrigation cycles depend on temperature and radiation levels.

Raspberries were harvested exclusively by hand from June to November, depending on the cultivar. Harvest workers undergo training and are then assigned to designated teams. Each team consists of 21 people and is led by a foreman responsible for coordinating the group's work. Harvesting was carried out in sections, depending on the cultivar and degree of fruit maturity. The productivity of individual teams varied greatly. Harvesting was done into crates, each containing 12 small containers of raspberries (125 g each).

Figure 2. Manual raspberry harvesting into crates

After weighing, the harvested raspberries are transported to the packing facility, where they are cooled, sorted, and packed according to the specific requirements of domestic and international buyers. The fruit prepared for sale is stored in a cold room at a temperature of 3-4°C.

Research results

According to the methodology adopted in the study, Tables 2 and 3 present the results related to labor inputs for raspberry harvesting in July and August, with separate values for the individual components T_1–T_5, as well as time losses T_{01} and working time T_{02}.

For the cultivars studied in July, the total harvest time T_{07} averaged 240.7 rbh·ha^{-1} and ranged from 71.6 to 516.5 rbh·ha^{-1}. Its variation is reflected by the standard deviation (104.2 rbh·ha^{-1}) and a coefficient of variation of 43.3% (Table 2). Considering the July harvest times for the analyzed cultivars, the highest value was recorded for Malling Bella, with an average of 246.3 rbh·ha^{-1}, while the lowest was noted for Kwanza (187.7 rbh·ha^{-1}).

The effective working time T_1 in July averaged 190.4 rbh·ha^{-1}, ranging from 39.4 to 465.5 rbh·ha^{-1}. Its high variability is indicated by the standard deviation (92.5 rbh·ha^{-1}) and a coefficient of variation of 48.6%. Among the analyzed cultivars, the highest effective harvest time was observed for Diamond Jubilee at 233.8 rbh·ha^{-1}, while the lowest value was recorded for Kwanza at 141.9 rbh·ha^{-1}.

Table 2 also presents the labor inputs (excluding effective time) for the individual groups of activities recorded during the workday study. Overall, the highest inputs were associated with transport time T_3 (an average of 20.9 rbh·ha^{-1}), while the lowest were recorded for break time T_5 (an average of 2.5 rbh·ha^{-1}). Time losses T_{01} and working time T_{02}, which were used as input data for calculating the efficiency indicators, amounted in July to an average of 50.3 and 222.6 rbh·ha^{-1}, respectively.

Table 2
Classification of working time for raspberry harvesting in July

Cultivar	Parametr	Raspberry harvest time in July (rbh·ha⁻¹)							
		Effective time	Auxiliary time	Transport time	Handling time	Break	Total harvest time	Time losses	Working time
		T_1	T_2	T_3	T_4	T_5	T_{07}	T_{01}	T_{02}
Kwanza	Minimum	61.7	3.6	6.4	2.9	0.7	75.3	13.6	71.7
	Average	141.9	9.9	20.5	13.1	2.3	187.7	45.8	172.3
	Maximum	312.4	19.7	46.0	34.2	5.3	374.6	105.1	356.4
	Standard deviation	54.9	4.2	8.9	6.4	1.0	65.7	19.9	61.4
	% CV	38.7	41.9	43.7	49.0	43.4	35.0	43.4	35.6
Malling Bella	Minimum	39.4	4.3	6.3	5.2	0.8	77.4	16.9	64.6
	Average	193.8	11.9	21.3	16.6	2.6	246.3	52.5	227.0
	Maximum	465.5	19.2	38.6	31.6	4.5	516.5	89.0	497.9
	Standard deviation	112.9	4.0	8.5	6.2	0.9	119.7	18.8	116.7
	% CV	58.2	33.5	39.7	37.1	35.8	48.6	35.8	51.4
Dia-mond Jubille	Minimum	57.8	3.2	5.9	4.0	0.7	71.6	13.8	66.9
	Average	233.8	11.9	21.0	17.0	2.6	286.3	52.5	266.7
	Maximum	367.3	23.8	38.4	29.4	4.8	451.9	96.4	422.2
	Standard deviation	78.7	5.5	9.1	7.5	1.1	98.3	22.6	90.9
	% CV	33.7	46.1	43.2	43.9	43.0	34.3	43.0	34.1
Overall	Minimum	39.4	3.2	5.9	2.9	0.7	71.6	13.6	64.6
	Average	190.4	11.3	20.9	15.6	2.5	240.7	50.3	222.6
	Maximum	465.5	23.8	46.0	34.2	5.3	516.5	105.1	497.9
	Standard deviation	92.5	4.6	8.7	6.9	1.0	104.2	20.5	99.2
	% CV	48.6	41.2	41.7	44.0	40.8	43.3	40.8	44.6

For the cultivars analyzed in August, the total harvest time T_{07} averaged 153.2 rbh·ha^{-1} and ranged from 5.5 to 612.0 rbh·ha^{-1}. Its extremely high variability is reflected by the standard deviation (158.1 rbh·ha^{-1}) and a coefficient of variation of 103.2% (Table 3). Considering the August harvest times for the evaluated cultivars, the highest value was recorded-similar to July-for Malling Bella (an average of 241.4 rbh·ha⁻¹), while the lowest was noted for Enrosadira (44.6 rbh·ha⁻¹).

Tabela 3
Classification of working time for raspberry harvesting in August

Cultivar	Parametr	Raspberry harvest time in August (rbh·ha⁻¹)							
		Effective time	Auxiliary time	Transport time	Handling time	Break	Total harvest time	Time losses	Working time
		T_1	T_2	T_3	T_4	T_5	T_{07}	T_{01}	T_{02}
Malling Bella	Minimum	17.2	0.7	1.6	1.1	0.2	20.8	3.6	19.5
	Average	192.5	11.1	19.7	15.6	2.4	241.4	48.9	223.4
	Maximum	491.1	29.5	45.4	39.9	6.0	612.0	120.9	566.1
	Standard deviation	133.2	8.0	13.4	10.8	1.7	165.5	33.3	153.6
	CV, %	69.2	71.6	67.8	69.0	68.0	68.5	68.0	68.8
Enrosadira	Minimum	4.7	0.2	0.4	0.2	0.0	5.5	0.8	5.3
	Average	33.9	2.2	4.7	3.3	0.5	44.6	10.7	40.7
	Maximum	60.1	4.8	11.4	7.8	1.2	83.6	23.5	75.7
	Standard deviation	17.5	1.5	3.3	2.3	0.4	24.5	7.3	21.9
	CV, %	51.7	67.4	69.3	70.0	67.9	54.9	67.9	53.7
Diamond Jubille	Minimum	4.3	0.2	0.6	0.3	0.1	5.5	1.2	5.2
	Average	68.5	2.5	5.4	3.9	0.6	81.0	12.5	76.5
	Maximum	267.8	14.7	29.9	23.3	3.6	339.2	71.4	312.3
	Standard deviation	96.8	4.2	8.6	6.8	1.0	114.3	20.6	107.5
	CV, %	141.2	167.5	158.5	173.0	165.1	141.1	165.1	140..6
Overall	Minimum	4.3	0.2	0.4	0.2	0.0	5.5	0.8	5.2
	Average	122.6	6.8	12.5	9.7	1.5	153.2	30.6	141.9
	Maximum	491.1	29.5	45.4	39.9	6.0	612.0	120.9	566.1
	Standard deviation	127.4	7.5	12.8	10.3	1.6	158.1	31.8	146.8
	CV, %	104.0	109.6	101.8	105.7	104.0	103.2	104.0	103.4

The effective working time T_1 in August averaged 122.6 rbh·ha⁻¹ and ranged from 4.3 to 491.1 rbh·ha⁻¹. This time showed very high variability, as indicated by the standard deviation (127.4 rbh·ha⁻¹) and the coefficient of variation of 104.0%. Among the analyzed cultivars, the highest effective harvest time was recorded for Malling Bella at 192.5 rbh·ha⁻¹, while the lowest was noted for Enrosadira at 33.9 rbh·ha⁻¹. Table 3 also presents the labor inputs for individual activity groups (in addition to effective time) recorded during the workday study in August. As in July, the highest inputs were associated with transport time T_3, averaging 12.5 rbh·ha⁻¹, while the lowest were recorded for break time T_5, averaging 1.5 rbh·ha⁻¹. Time losses T_{01} and working time T_{02} used for calculating the efficiency indicators amounted in August to an average of 30.6 and 141.9 rbh·ha⁻¹, respectively.

Table 4 presents the effective harvest time utilization coefficients K_{07} for manual raspberry harvesting for each cultivar in July and August. In July, these coefficients averaged 0.78 and ranged from 0.49 to 0.90. Their low variability is reflected by the standard deviation (0.09) and the coefficient of variation of only 11.4%. Considering the July values for individual cultivars, Diamond Jubilee showed the highest coefficient (average 0.82), while the lowest was observed for Malling Bella (0.75).

Table 4
Effective harvest time utilization coefficients K_{07}

Parametr	Cultivar				
	Kwanza	Malling Bella	Enrosadira	Diamond Jubille	Overall
July					
Minimum	0.59	0.49	-	0.74	0.49
Average	0.76	0.75	-	0.82	0.78
Maximum	0.86	0.90	-	0.89	0.90
Standard deviation	0.07	0.12	-	0.03	0.09
CV, (%)	9.6	16.3	-	4.1	11.4
August					
Minimum	-	0.63	0.68	0.72	0.63
Average	-	0.80	0.78	0.82	0.80
Maximum	-	0.87	0.85	0.95	0.95
Standard deviation	-	0.05	0.05	0.06	0.05
CV, (%)	-	6.0	6.7	7.6	6.7

In August, the calculated coefficients were higher compared to July, averaging 0.80 and ranging from 0.63 to 0.95. They also showed low variability (standard deviation 0.05, coefficient of variation 6.7%). For the cultivars analyzed in August, the highest K_{07} values-similar to July-were recorded for Diamond Jubilee (average 0.82), while the lowest were observed for Enrosadira (0.78).

The value of the calculated K_{07} coefficients for effective harvest time utilization was strongly influenced by the additional activities performed by workers during raspberry harvesting (according to the working time classification for manual harvesting). The duration of these activities was identified in the study as time losses T_{01}: the time spent collecting the cart, containers, and crates; the time needed to reach the row with the cart; the time spent rearranging crates; the time required to transport full crates to the weighing station; waiting time in the weighing queue; weighing time; sorting time; time spent collecting crates and containers again; the time required to return empty crates to the harvesting area; and break time.

To evaluate the efficiency of manual raspberry harvesting, the working time utilization coefficients K_{02} and the effective harvest time utilization coefficients K_{07} were calculated and compared. The results for the cultivars harvested in July are shown in Figure 3, and those for the cultivars harvested in August in Figure 4.

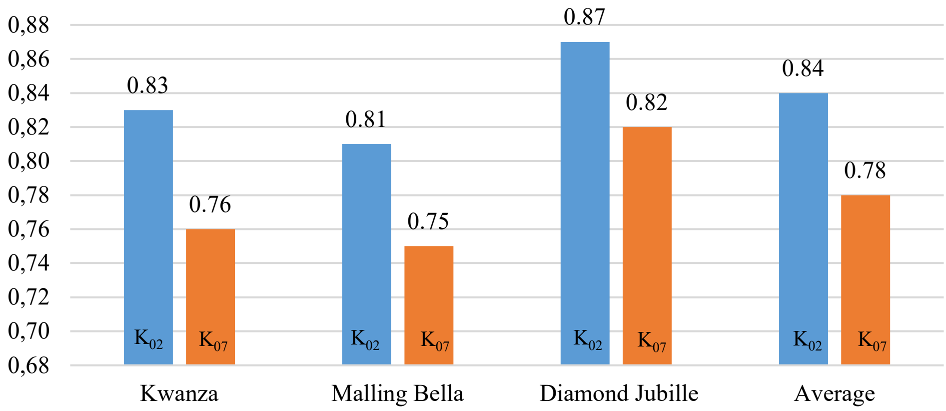

Figure 3. Working time utilization and effective harvest time utilization coefficients for the cultivars harvested in July

The presented results show how strongly the effective harvest time T_1 in July was influenced by the additional time spent on auxiliary activities T_2 and transport time T_3. In this case, the K_{02} values averaged 0.84 (while K_{07} was 0.78). Among the analyzed cultivars, the highest working time utilization coefficients were recorded for Diamond Jubilee (0.87), with an effective time utilization of 0.82. The lowest values were noted for Malling Bella: 0.81 and 0.75, respectively (Fig. 3).

Similarly, the results shown in Figure 4 for August illustrate the significant impact of auxiliary activities T_2 and transport time T_3 on the effective harvest time T_1. In this period, the K_{02} values averaged 0.86 (while K_{07} was 0.80). As in July, Diamond Jubilee showed the highest working time utilization coefficient (0.88), with an effective time utilization of 0.82. The lowest values were recorded for Enrosadira: 0.84 and 0.78, respectively.

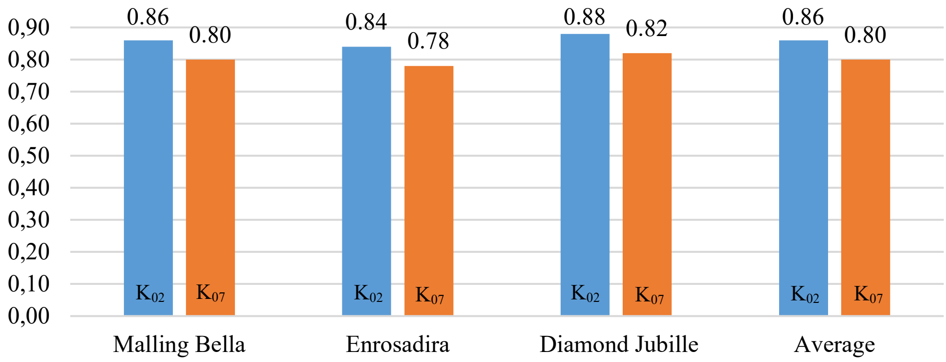

Figure 4. Working time utilization and effective harvest time utilization coefficients for the cultivars harvested in August

To evaluate the organization of manual raspberry harvesting, the transport time utilization coefficients K_t and the handling time utilization coefficients K_{cm} were also calculated and compared. The results for the cultivars analyzed in July are shown in Figure 5, and those for the cultivars analyzed in August in Figure 6.

In July, the K_t values averaged 0.43, while the K_{cm} values averaged 0.31 (Fig. 5). Comparing the coefficients for the studied cultivars, the highest transport time utilization value was recorded for Kwanza (0.45), with a handling time utilization coefficient of 0.28. The lowest values were characteristic of Malling Bella (0.40), while its handling time utilization coefficient was 0.33, which was higher than that observed for Kwanza.

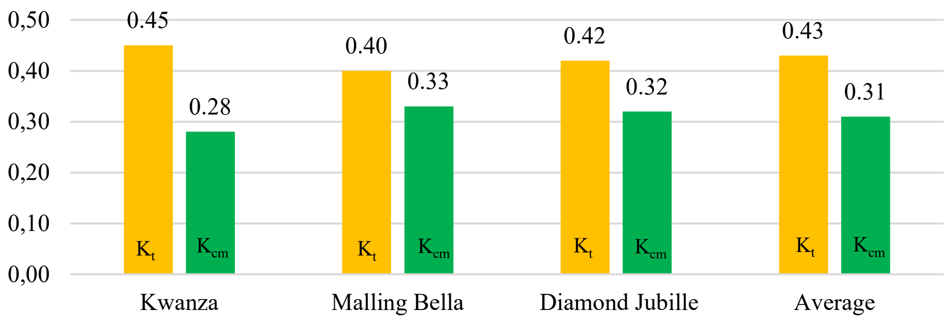

Figure 5. Transport time utilization and handling time utilization coefficients for the cultivars harvested in July

Considering the coefficients evaluated for August (Fig. 6), the K_t values averaged 0.44 and the K_{cm} values averaged 0.30. Among the cultivars studied, the highest transport time utilization was recorded for Diamond Jubilee (0.46), with a handling time utilization coefficient of 0.29. The lowest values were noted for Malling Bella (0.42), with handling time utilization at 0.31. Overall, it should be emphasized that the handling time utilization coefficients in August showed little variation between cultivars, ranging from 0.29 to 0.31.

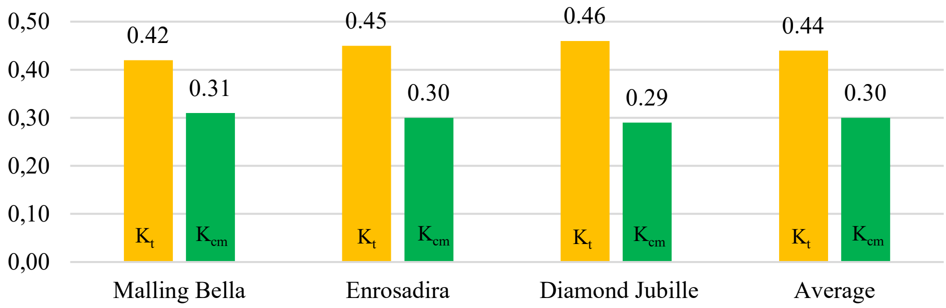

Figure 6. Transport time utilization and handling time utilization coefficients for the cultivars harvested in August

Discussion

The results obtained confirm that manual raspberry harvesting is a highly labor-intensive process and is very sensitive to both cultivar-related and organizational factors. The share of effective time T_1 in the total harvest time T_{07} ranged from 52% to 62%, while the K_{07} coefficient values fell between 0.49 and 0.95. This means that 40-50% of total working time consisted of activities other than the actual fruit picking. These findings align with broader research in horticultural and agricultural production, which highlights the dominant share of labor costs in total production costs (Simnitt & Martin, 2022; Win, 2025; Paszko, 2008; Wróblewska et al., 2019). This indicates that raspberry harvesting is particularly well suited for organizational optimization and modeling.

Under the tunnel-grown production conditions analyzed in the study, differences between cultivars proved to be significant. The Diamond Jubilee cultivar showed the highest values of both the K_{07} and K_{02} coefficients in both analyzed months (0.82 for K_{07} and 0.87-0.88 for K_{02}), meaning that working time was used more efficiently compared to Kwanza, Malling Bella, and Enrosadira. This may result from a combination of yield potential and plant architecture (plant structure, fruit placement on the canes, and the share of marketable fruit), which-as emphasized by Danek (2014), Bobinaitė et al. (2016), and Baldassi et al. (2024)-varies significantly between raspberry cultivars. Cultivars with well-exposed and evenly distributed fruit tend to require less time per picking operation and reduce the share of auxiliary tasks, which directly translates into higher K_{07} values.

In contrast, despite high effective harvest time T_1 (reflecting high yields), the Malling Bella cultivar showed lower K_{07} values in July (0.75) and a relatively higher share of time losses. This may indicate that high yield levels also increase the number of accompanying operations - more frequent emptying of containers, more transport trips to the weighing station, and greater load on sorting points. This interpretation is consistent with observations reported by other authors studying labor inputs and technical efficiency in specialized farms (Malaga-Toboła et al., 2013; Kwaśniewski et al., 2013; Marzec et al., 2019; Kuboń, 2018; Góral & Rembisz, 2018), who note that increasing production scale does not always lead to a proportional increase in labor efficiency, especially when the work organization system is not sufficiently adjusted to the production conditions.

The variation in results over the course of the season is also highly significant. In July, the total harvest time T_{07} was clearly higher (an average of 240.7 rbh·ha^{-1}) than in August (153.2 rbh·ha^{-1}), while the effective harvest time utilization coefficients K_{07} were slightly lower (0.78 in July compared with 0.80 in August. This suggests that during the peak season, when yields are high, the organization and logistics system becomes more heavily loaded, increasing the share of auxiliary and transport activities. Similar patterns are described by Apáti (2014) and Wróblewska et al. (2019), who note that raspberry production involves short, highly intensive harvesting periods during which labor shortages and organizational constraints become critical factors affecting profitability. The results confirm that during such periods, it is especially important to properly adjust the number and structure of harvesting teams, as well as internal transport arrangements, to the fruit ripening dynamics.

Within the context of previous analyses of agricultural labor inputs (e.g., Malaga-Toboła et al., 2013; Kwaśniewski et al., 2013; Kuboń, 2018), the detailed structure of time losses T_{01} is particularly noteworthy. The study found that transport-related time T_3 accounted for a considerably larger share of losses than handling-related time T_4. The transport time utilization coefficients K_t averaged 0.43 in July and 0.44 in August, while the handling time utilization coefficients Kcm were lower (0.31 and 0.30). This indicates that managing the flow of harvested raspberries (from the harvest row to the weighing station and the cooling facility) offers greater optimization potential than handling operations involving crates and containers. This aligns with the logistical approach to agricultural production processes, in which shortening transport routes, eliminating unnecessary delays, and improving the sequencing of tasks during harvesting are considered essential (Matuszek, 2016).

The obtained K_{02} values (0.84 in July and 0.86 in August) indicate that work organization during raspberry harvesting is relatively efficient, but there is still potential for improvement-primarily by reducing transport time and improving the placement of weighing stations and crate collection points. In this context, the results are consistent with findings from Mielczarek (2009) and Matuszek (2016), who emphasize that even with well-organized manual work, bottlenecks often arise at the interface between the production process and internal logistics.

In relation to the broader discussion about mechanizing raspberry harvesting, these results help clarify both the limitations and the opportunities for improving manual harvesting. Marković et al. (2017) showed that mechanical harvesting can be 3-4 times cheaper than manual harvesting; however - as pointed out by Mika et al. (2016) - the quality of mechanically harvested fruit is lower, which limits the applicability of this technology for fresh-market production. On the studied plantation, which is oriented toward high-quality fresh fruit, manual harvesting remains the preferred approach. This means that the main direction for improving efficiency should focus not on replacing human labor with machines, but on optimizing work organization and logistics to minimize time losses while maintaining high fruit quality.

At this point, the potential for using the obtained results in modeling the raspberry harvesting process becomes clearly visible. According to the approach presented by Sokolowski & Banks (2010) and Mielczarek (2009), discrete-event simulation is particularly useful for analyzing short, repetitive processes such as soft fruit harvesting. The coefficients K_{07}, K_{02}, K_t, and Kcm, along with the detailed data on the time structure T_1-T_5 and T_{01}, can serve as direct input variables for simulation models that represent:

- different scenarios of organizing soft fruit harvesting teams (number of workers, task allocation, rotation between harvesting sectors),
- different spatial layouts of the plantation and locations of weighing points,
- strategies for organizing internal transport (number of carts, route lengths, frequency of transport runs).

In turn, as shown in the works of Nguyen (2021) and Tüskıner & Bilgen (2021), linear, integer, and stochastic programming models can be used to optimize harvest scheduling and to link field processes with subsequent stages of the supply chain (cooling, sorting, packing, shipping).

The parameters determined in this study-such as unit labor inputs (rbh·ha^{-1}) for individual cultivars and for different periods of the harvesting season, as well as the calculated coefficients describing the organization of manual raspberry harvesting-can be used for:

- constructing objective functions that minimize total labor costs while meeting harvesting timing and logistics capacity constraints,
- determining the optimal number of workers for individual days of the harvest season,
- planning the allocation of cultivars to harvesting sectors in a way that balances workload across all members of the harvesting team, thus improving the use of available seasonal labor resources.

From an economic perspective, the results are consistent with the findings of Paszko (2008), Simnitt & Martin (2022), and Wróblewska et al. (2019), who emphasize that fluctuations in labor costs and labor availability can significantly affect the profitability of berry production. The coefficients and time structures proposed in this study can therefore be incorporated into models assessing the economic viability of raspberry production under various organizational scenarios, taking into account both wage changes and the risk of labor shortages.

It should be emphasized that although the research was conducted on a single, highly specialized tunnel-grown plantation, the obtained results align with general trends described in the literature on berry fruit production (Bulatović, 2020; KOWS Report 2021; Industry Reports 2024). The identified structure of time categories and efficiency coefficients can serve as a universal reference point for further comparative research in different cultivation systems (soil-based and container-based), varied irrigation technologies, and alternative work organization models.

In summary, the study not only enabled a quantitative assessment of manual raspberry harvesting efficiency for selected cultivars but also provided input data for modeling and simulation of harvesting processes. By combining the classical CIOSTA methodology (time studies and workday photography) with a systemic and logistical perspective, a foundation has been established for developing simulation and optimization models that may support the design of organizational solutions for raspberry harvesting-and more broadly, for the harvesting of other berry crops.

Summary

1. The efficiency of manual raspberry harvesting was influenced primarily by the organization of the harvest, which depended not only on the effective harvesting time but also on the time allocated to additional activities necessary for completing the process. These additional activities included auxiliary tasks (T_2), transport-related tasks (T_3), and handling tasks (T_4).
2. The effective harvest time utilization coefficients K_{07} in July averaged 0.78 (ranging from 0.49 to 0.90). Among the studied cultivars, the highest values were recorded for Diamond Jubilee (average 0.82), and the lowest for Malling Bella (0.75). In August, the coefficients were higher compared to July, averaging 0.80 (ranging from 0.63 to 0.95). As in July, Diamond Jubilee showed the highest values in August (average 0.82), while the lowest were observed for Enrosadira (0.78). Differences in work efficiency between cultivars and organizational variants indicate the need to include these factors in mathematical and simulation modeling. This will allow the development of organizational scenarios tailored to cultivation conditions and cultivar characteristics.
3. The results indicate that transport-related time T_3 (i.e., time spent reaching the row with the cart, transporting full crates to the weighing station, returning empty crates to the picking area, and returning the cart after harvest) contributed much more to total time losses T_{01} than handling-related time T_4 (i.e., rearranging crates, weighing, and sorting raspberries). The identified parameters - such as effective time, unit productivity, and labor cost intensity - can be used as input variables for simulation and optimization models supporting organizational decisions in horticultural farms.
4. The transport time utilization coefficients K_t averaged 0.43 in July and 0.44 in August. The handling time utilization coefficients K_{cm} were lower, amounting to 0.31 in July and 0.30 in August.
5. The results of the study provide a basis for developing a comprehensive model of raspberry harvest organization, which can be used both in comparative analyses and in practical orchard management, supporting decision-making related to work organization.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author due to various file formats.

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MODELOWA OCENA EFEKTYWNOŚCI RĘCZNEGO ZBIORU MALIN Z WYKORZYSTANIEM METODYKI CIOSTA W SYSTEMACH UPRAW TUNELOWYCH

Streszczenie. Celem pracy była ocena wpływu odmiany malin oraz organizacji procesu pracy na efektywność zbioru ręcznego w warunkach intensywnej uprawy tunelowej. Badania przeprowadzono w lipcu i sierpniu 2022 r. na plantacji o powierzchni 20 ha, obejmując cztery odmiany: Kwanza, Malling Bella, Enrosadira i Diamond Jubilee. Zastosowano metodykę CIOSTA, obejmującą chronometraż i fotografię dnia pracy, co pozwoliło na szczegółową analizę czasów efektywnych, pomocniczych, transportowych oraz strat pracy. W lipcu średni całkowity czas zbioru wynosił 240,7 rbh·ha^{-1}, a w sierpniu 153,2 rbh·ha^{-1}. Najwyższą efektywność uzyskano dla odmiany Diamond Jubilee (K_{07} = 0,82), natomiast najniższą dla Malling Bella w lipcu oraz Enrosadiry w sierpniu. Największy udział strat czasu stanowiły czynności transportowe, co potwierdzają wartości współczynnika K_t (0,43–0,44). Wyniki wskazują, że efektywność zbioru zależy nie tylko od odmiany, lecz także od organizacji pracy i logistyki wewnętrznej. Uzyskane wyniki potwierdzają, że efektywność zbioru malin zależy nie tylko od odmiany i potencjału plonotwórczego roślin, lecz także od struktury organizacyjnej procesu, zwłaszcza logistyki transportu wewnętrznego. Przedstawione analizy dostarczają danych wejściowych do tworzenia modeli symulacyjnych i optymalizacyjnych, wspierających projektowanie usprawnień pracy w gospodarstwach ogrodniczych. Badanie wpisuje się w aktualny nurt analiz organizacyjno-logistycznych w produkcji ogrodniczej oraz stanowi podstawę do opracowania modelowych rozwiązań procesu zbioru owoców miękkich.

Słowa kluczowe: maliny, zbiór, organizacja pracy, efektywność, chronometraż, optymalizacja