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Theoretical foundations of the formation of yield and quality of asparagus shoots depending on the duration of harvesting

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Abstract. The relevance of the study is conditioned by the growing demand for asparagus and the need to increase the efficiency of its cultivation in Ukraine, considering the biological characteristics of the crop and economic factors of production. The purpose of the study was to theoretically substantiate

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the influence of the duration of harvesting asparagus shoots on the development of yield, biometric and qualitative indicators of products, and the durability of plantings. The paper used methods of analysis, generalisation, and systematisation of the results of contemporary national and international scientific research focused on the physiology of asparagus plant growth, cultivation practices, and the regulation of assimilatory apparatus recovery processes in asparagus plants. The relationship between the duration of the shoot harvesting period and plant productivity, and the processes of accumulation of reserve nutrients in rhizomes, was investigated. It was found that prolonged harvesting causes depletion of plants and reduces their ability to restore the assimilation apparatus after harvesting. It has been established that extending the harvesting period excessively leads to a reduction in shoot diameter, a decline in their marketability, and a deterioration in the quality characteristics of the produce. It was determined that the optimally limited duration of harvesting contributes to stable crop development and ensures high shoot quality indicators. The physiological and economic aspects of the use of plantings were analysed and it was found that the effective operation of plantations is limited to 8-10 years due to morphophysiological ageing of the root system and violation of carbohydrate metabolism. It was generally accepted that regulation of the duration of harvesting is a key element of asparagus cultivation technology. The practical significance of the study lies in the possibility of using the results obtained by agricultural producers, farms, and scientific institutions to optimise asparagus cultivation technologies in Ukraine

Keywords: *Asparagus officinalis*; shoots; carbohydrates; plant productivity; biometric indicators; product quality

Introduction

The relevance of the study is conditioned by the growing demand for asparagus as a valuable early vegetable crop and the expansion of its production in Ukraine in the context of the transformation of the agricultural sector. Improving the efficiency of asparagus cultivation is important both from a practical standpoint – to ensure stable yields and profitability of production, and from a theoretical standpoint – to deepen knowledge about the physiological mechanisms of crop productivity. Special attention should be paid to optimising the elements of cultivation technology, among which the duration of shoot harvesting plays a key role. Insufficient scientific substantiation of this factor in the conditions of Ukraine leads to a decrease in product quality, premature depletion of plants, and a reduction in the service life of plantings. In the conditions of climate change and rising production costs, the issue of rational management of the production process is becoming particularly relevant. Simultaneously, there is a need to systematise scientific data on the influence of the duration of harvesting on the physiological state of plants and their longevity. Thus, the investigation of this issue is important for the development of scientifically based approaches to improving the efficiency of asparagus cultivation in Ukraine.

Asparagus (*Asparagus officinalis* L.) it is a perennial herbaceous plant of the family *Asparagaceae*, native to the Mediterranean region. Asparagus combines nutritional and aesthetic value. It is grown as a vegetable crop and as an ornamental plant, widely used in landscaping and floristry. Young shoots are used for food. Under favourable conditions, the aboveground part of the plant grows all year round. Under continental climatic conditions, the stems die back in autumn, while new shoots emerge in spring from overwintering buds located on the perennial rhizome. According to I.L. Havrys &

V.B. Kutovenko (2022), the crop is characterised by a high potential of use, which expands its market opportunities. D. Drost (2020) emphasised that one of the main technological factors that determine the economic efficiency of production is the duration of the harvest period, which directly affects both the quantitative indicators of yield, and the quality of products and the duration of use (durability) of the plantation. The lack of scientific and rational planning of cultivation leads to a decrease in the quality and yield of asparagus shoots.

Asparagus is one of the earliest vegetable crops produced in open-field conditions and is gaining increasing popularity in Ukraine among both consumers and producers. The level of yield of asparagus shoots depends on many factors, namely – the assortment, the quality of planting material, the age of plants (plantations), the assortment, soil and climatic conditions of cultivation, elements of cultivation technology, duration of harvesting. According to T.V. Ivchenko *et al.* (2025), interest in industrial asparagus cultivation is growing in Ukraine; however, individual industrial crops remain insufficiently adapted to local soil and climatic conditions.

A special feature of asparagus as a perennial crop is the close relationship between the productivity of the current year and the physiological state of plants in the previous growing season. Shoot yield development depends on reserve carbohydrates accumulated in the rhizome and fleshy roots, making harvest duration a critically important cultivation parameter. It is the duration of the harvesting period that determines not only the current yield and marketable indicators of products, but also the physiological state of plants, the accumulation of reserve substances in the rhizome, and the long-term productivity of the plantation. The question of the role of carbohydrate metabolism in the development of yield was considered in detail by B. Santiago *et al.* (2021). The researchers investigated the processes of assimilate accumulation and mobilisation and concluded that the balance between their use during harvesting and recovery after it is crucial for stable plant productivity. The studies by Q. Yu & L. Fan (2021) and M. Travesset (2025) showed that a violation of this balance leads to a decrease in the intensity of growth processes and a deterioration in the quality of shoots.

Yield potential of asparagus (*Asparagus officinalis* L.) depends on the presence of soluble carbohydrates (CHO) in the storage root system of the plant. Research by A. Casas *et al.* (2023) showed that sufficient levels of CHO are necessary not only for shoot development during the harvest period, but also after harvesting, which, in turn, is important for replenishing CHO reserves. Hence, the ability of asparagus plants to accumulate, move, and store enough CHO is crucial for maintaining plant productivity in both current and subsequent crops.

In scientific studies of recent decades, it has been established that asparagus is an extremely sensitive crop to the intensity and duration of harvesting, since shoots are formed due to carbohydrate reserves accumulated in underground organs during the previous growing season. Excessive or too long harvesting of shoots disrupts the balance between the use and restoration of these reserves, which negatively affects the growth, morphological indicators, and physiological stability of plants. Contemporary research by L. Mašková *et al.* (2023) and F.J. Lopez-Moreno *et al.* (2025) confirmed that excessive duration of the harvest period leads to a violation of the balance between assimilation and consumption of plastic substances, a decrease in plant viability, and a reduction in the productive period of the plantation. Meanwhile, a harvest period that is too short limits the crop's potential yield. The duration of the harvesting period significantly affects the balance between consumption and accumulation of assimilants in the rhizome. Excessive duration of the harvesting period negatively affects the viability of plantations.

Research by T.V. Ivchenko *et al.* (2021) pointed out that despite a significant amount of research in Western Europe and America, the problem of optimising the duration of harvesting asparagus shoots remains relevant for Ukraine, where climatic conditions and soil structure differ significantly. Asparagus is an important crop for intensive vegetable growing in Ukraine. Its multi-year development cycle requires clear planning of the investment period. In the classical literature, the service life of plantings was often determined in the range of 15-20 years. However, intensive cultivation technologies, the use of F_1 hybrids, and changing market requirements regarding shoot grading necessitate a revision of these terms. In a market economy, the main factor is not the biological life span of the plant, but the period of maximum return on high-quality first-class products. Therefore, generalisation of the results of international research and their adaptation to Ukrainian conditions is an urgent issue.

The purpose of the study was to provide a theoretical generalisation and scientific substantiation of the influence of the duration of the harvesting period of asparagus shoots on the development of yield, product quality, and productive longevity of the plantation under present-day growing conditions. The objectives of the study were: to analyse contemporary scientific approaches to regulating the duration of harvesting asparagus shoots; to generalise the influence of the duration of harvesting on the yield and biometric indicators of shoots; to determine the relationship between the duration of harvesting, product quality, and the supply of carbohydrates in rhizomes; to substantiate the areas of further research in the conditions of Ukraine.

Materials and Methods

The study was conducted in a theoretical and applied format with elements of meta-analysis of sources published in 2002-2025. The analysis involved research papers from journals indexed in Scopus and Web of Science, materials of professional journals and scientific collections, monographs, textbooks, materials of international conferences, and Ukrainian publications devoted to vegetable growing and physiology of perennial crops. The methodology included a systematic analysis of literature sources, which helped to identify current trends in asparagus cultivation, assess the impact of the duration of shoot harvesting on plant physiological processes and productivity, and identify gaps and contradictions in published data. The relationship between the duration of the harvest period and changes in productivity indicators, such as the total yield of shoots, average weight and diameter, marketable yield composition, the physiological state of plants, and the dynamics of carbohydrate reserves in rhizomes, was studied using a comparative analysis of experimental results. The use of the method of generalisation of regularities identified key trends in the dependence of economic indicators on the duration of harvesting, which helped to predict the productivity of perennial plantations.

Theoretical forecasting was used to estimate the optimal duration of asparagus harvesting considering the physiological state of the plants, providing an integrated assessment of long-term productivity. Statistical processing of the results was performed using the methods of variance and correlation analysis using specialised Excel and DAD software suites, which helped to assess the relationships between indicators and establish the significance of the results obtained (France & Thornley, 2007). The methodological basis of the study was a systematic approach that considered the physiological processes of perennial plantings and agrotechnical factors, which provided a comprehensive analysis of the productivity and quality of shoots. The study employed general scientific methods, including analysis, synthesis, induction, comparison, abstraction, and modelling, which enabled logical structuring of the material, integration of quantitative and qualitative indicators, and substantiated interpretation of results regarding optimisation of asparagus harvesting duration.

Results and Discussion

The development of shoot weight and quality in asparagus occurs due to reserve carbohydrates (Wilson *et al.*, 2002; Feller & Müller, 2018; Kutovenko *et al.*, 2018) accumulated in the rhizome during the previous growing season. During the harvesting period, the shoots were cut before the beginning of photosynthetic activity, which made it impossible to compensate for the costs of assimilants. After the end of the harvest period, the plant enters the phase of active vegetative growth, forming branched aboveground stems with cladodes – vegetative tissue that carries out photosynthesis and carbohydrate accumulation. Thus, there is a close physiological relationship between the harvesting period and the assimilation period, which determines the crop productivity.

According to P.J. Paschold *et al.* (2002) carbohydrate reserves in the asparagus rhizome are a crucial factor limiting the number and weight of shoots in the next season. Too intensive use of carbohydrates from rhizomes without enough time to restore them leads to a decrease in the diameter of shoots, a decrease in yield, and a weakening of plants.

The balance of reserve substances can be described by the equation:

$$B = A - E, \quad (1)$$

where B – balance of carbohydrates; A – accumulation of assimilants; E – cost of forming shoots. Over a long harvesting period, the value of E exceeds A, which leads to plant depletion. The duration of harvesting asparagus shoots usually varies from 4 to 8 weeks, depending on the age of the plantation, variety, climatic conditions, and cultivation technology. In the first years of operation of plantings, a short harvesting period of up to 3 weeks is recommended, which contributes to better development of the root system, the development of a strong plant, and the accumulation of nutrients. D. Drost (2023) and H.Ya. Slobodianyk *et al.* (2015) found that extending the harvesting period from 6 to 8 weeks leads to an increase in the total crop weight in the current season, but is accompanied by a decrease in the average weight of shoots and a deterioration in their commercial quality. In addition, the following year there was a decrease in yield and an increase in the proportion of thin shoots.

M. Knaflewski *et al.* (2012) in studies in temperate climates showed that the optimal duration of harvesting should consider not only the economic indicators of the current year, but also the long-term stability of plantation productivity. Excessive duration of the harvesting period reduced the viability of plants and shortened the period of their economic use. Asparagus yield is a complex indicator that is determined by the number of shoots, their average weight, and the structure of commercial products. Extending the harvesting period contributes to the growth of the total amount of products obtained only to a certain critical limit, after which plant depletion begins. An additional one to two weeks of harvesting may result in a short-term increase in yield, but negatively affect yields in subsequent years (Guo *et al.*, 2020; Drost, 2023). In the conditions of Ukraine, where the growing season is often accompanied by stressful factors (droughts, high temperatures), the negative impact of prolonged harvesting can be even more pronounced. Morphological and biometric indicators of shoots significantly depend on the physiological state of plants, which, in turn, is determined by the harvesting regime (Kutovenko *et al.*, 2020).

Analysis of the generalised literature data presented in Table 1 indicates a clear relationship between the duration of the harvesting period of asparagus shoots and the main indicators of its productivity. An increase in the duration of harvesting from 4 to 8 weeks is accompanied by significant changes in both quantitative and qualitative characteristics of shoots, which is conditioned by the specifics of the physiology of perennial crop and the specifics of the development of fruiting organs in the absence of photosynthetic activity.

Table 1. *Influence of the duration of harvesting on the yield of asparagus shoots (generalised data)*

Duration of harvest, weeks	Number of shoots, U/m²	Average shoot weight, g	Yield, t/ha
4	18.5	42.3	7.6
6	24.1	39.6	9.5
8	29.7	33.9	10.1

Source: data were summarised by the author based on J. Dyduch *et al.* (2014), H.Ya. Slobodianyk (2015), J.Y. Hong *et al.* (2025)

According to J. Dyduch *et al.* (2014), J.Y. Hong *et al.* (2025), extending the harvesting period leads to an increase in the total number of shoots that are formed and collected per unit area. Thus, for a four-week harvesting period, the number of shoots is on average 18.5 U/m², while with a six-week harvest, this figure increases to 24.1 U/m², and for eight weeks – up to 29.7 U/m². The data obtained indicate that asparagus plants can maintain the intensity of shoot regrowth for a long time (Fig. 1).

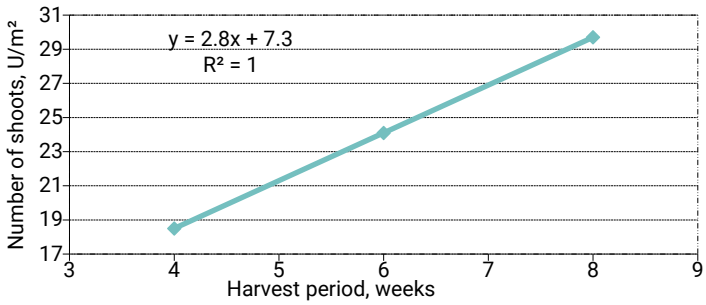

Figure 1. *Influence of the harvesting period on the development of the number of commercial shoots*

Source: data were summarised by the author based on J. Dyduch *et al.* (2014), H.Ya. Slobodianyk (2015), J.Y. Hong *et al.* (2025)

An increase in the number of shoots occurs due to a gradual decrease in the average weight of one shoot by T. Taguchi & S. Motoki (2022). During the four-week harvesting period, the average shoot weight was 42.3 g, during the six-week period – 39.6 g, and during the eight-week period it decreased to 33.9 g. This trend is natural and is explained by the growing competition between shoots for limited reserves of plastic substances. As the harvesting period is extended, carbohydrate reserves are gradually depleted, which limits the growth potential of each subsequent shoot (Fig. 2a). An important indicator of productivity is the total yield, which, according to the data provided, increases from 7.6 t/ha for four-week harvesting to 9.5 t/ha for six-week harvesting and 10.1 t/ha for eight-week harvesting. Thus, J.Y. Hong *et al.* (2025) showed that extending the harvesting period provides an increase in yield by increasing the number of shoots, even though their average weight decreases. However, it should be noted that the rate of yield growth is gradually decreasing: if an increase in the duration of harvesting from 4 to 6 weeks provides an increase in yield by 1.9 t/ha, then a further extension to 8 weeks – only by 0.6 t/ha. This indicates an approach to the biological limit of productivity of asparagus plants within the same growing cycle (Fig. 2b).

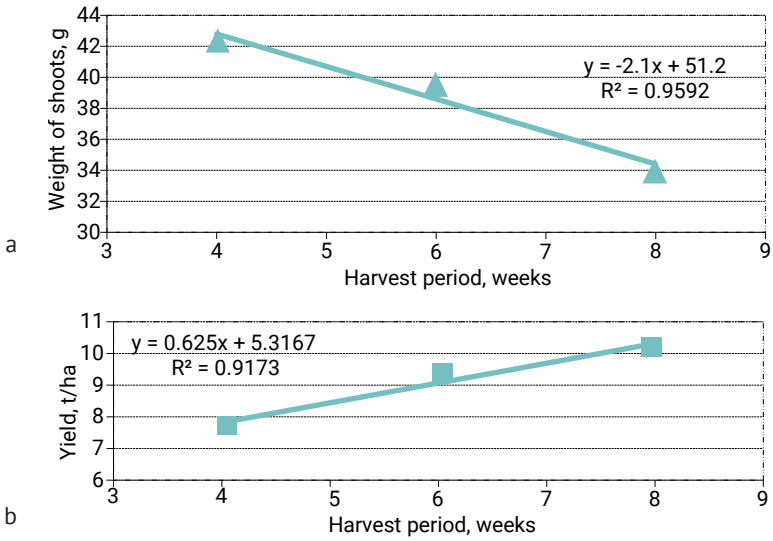

Figure 2. *Influence of harvesting time on shoot weight and yield*

Note: a – influence of harvesting time on the weight of commercial shoots; b – influence of harvesting time on commercial yield

Source: developed by the author based on T. Taguchi & S. Motoki (2022), J.Y. Hong *et al.* (2025), H.Ya. Slobodianyk *et al.* (2015), V.B. Kutovenko *et al.* (2020)

From a physiological standpoint, this dynamics is explained by the specific features of the development of the asparagus crop. During the harvesting period, the shoots are cut when they reach a height of 25-27 cm, which makes it impossible to form an assimilation apparatus and restore the reserves of organic substances, as reported by M. Knaflewski *et al.* (2012). All processes of shoot growth occur exclusively at the expense of reserve carbohydrates accumulated in the rhizome. The longer the harvesting period lasts, the more reserves are consumed, which gradually limits the growth potential of subsequent shoots and leads to a decrease in their weight and diameter.

Analysis of the above data also allows drawing a conclusion that the quality of products depends on the number of shoots. With a shorter harvesting period, shoots with a larger weight and better biometric indicators are formed, which, as a rule, have a higher commercial value. Extending the harvesting period, on the contrary, contributes to obtaining more shoots, but by reducing their average weight, which can negatively affect the marketability of the crop and compliance with the requirements of the premium market segment (Fig. 4). The obtained patterns are consistent with the findings of A. Zurawicz *et al.* (2008), who noted that for perennial asparagus plantations that are in the intensive exploitation stage, the optimal harvesting time for mature asparagus plantations is 6-7 weeks. It is during this period that the optimal ratio between the number of shoots, their average weight, and total yield is achieved, without significant depletion of plants. Extending harvesting to 8 weeks or more, although provides a certain increase in yield in the current year, in the long run may lead to a decrease in plantation productivity in subsequent years (Fig. 3). From an agrotechnological standpoint, the data obtained are of great practical importance. They indicate the need to regulate the duration of harvesting depending on the age of plantings, the level of agricultural background, and the general

condition of plants. Young asparagus plantations are particularly sensitive to the duration of the harvest period, since their root system is at the stage of active development, and the supply of plastic substances is limited. For such plantings, it is advisable to limit the duration of harvesting, even if this leads to low yields in the first years of operation.

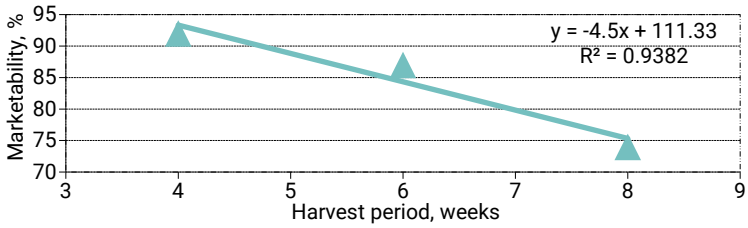

Figure 3. *Influence of harvesting time on the development of overall marketability of asparagus shoots*

Source: developed by the author based on P.J. Paschold *et al.* (2002), H.Ya. Slobodianyk *et al.* (2015), A. Siomos (2018)

Thus, the generalisation of the data given in Table 1 confirms that an increase in the duration of harvesting asparagus shoots is accompanied by an increase in the number of shoots and total yield, but simultaneously leads to a decrease in the average weight of shoots and gradual depletion of plants. This necessitates a search of an optimal balance between maximising the yield of the current year and ensuring stable productivity of plantations in the long term, which is a key task of contemporary technologies for growing asparagus in Ukraine.

It is advisable to use graphical interpretation of the results to visually display the identified patterns and better understand the nature of changes in the main performance indicators. In particular, Figure 1 showed the dependence of the duration of harvesting on the total yield of asparagus shoots, which was described by the linear regression equation. At the initial stage, with an increase in the duration of harvesting from 4 to 6 weeks, there was an intensive increase in yield conditioned by the active use of reserve carbohydrates of the rhizome and the high potential ability of plants to form new shoots. This period is characterised by a relatively high yield growth rate, which indicates the effective involvement of internal reserves of plants without critical disruption of their physiological state.

Further extension of the harvesting period to 8 weeks is accompanied by an increase in the overall yield, but the quality of products decreases due to a decrease in the thickness of shoots. This trend indicates a gradual approach of the "plant – crop" system to the limit of biological productivity within one growing season. Despite the increase in the gross harvest, the economic efficiency of each additional week of harvesting is significant. From a biological and technological standpoint, the shape of the curve confirms that the yield of asparagus cannot grow indefinitely by extending the harvesting period without considering the physiological state of plants, since the source of shoot growth is a limited supply of plastic substances. That is why it is advisable to consider the yield graph not only as a quantitative characteristic, but also as an indicator of the level of load on a perennial plant.

The indicators shown in Table 1 and Figure 1 reflect only an integral assessment of productivity and do not give a complete picture of changes in the morphological and qualitative characteristics of products during the extension of the harvesting period. In this regard, it is advisable to further analyse the biometric and qualitative indicators of shoots, which are more sensitive to the duration of harvesting and directly determine the commercial quality of products. It is precisely

such indicators as the average diameter of shoots, length, uniformity, density of tissues, absence of deformations, and fibrousness that allow assessing not only the quantitative, but also the qualitative aspect of the impact of the harvest duration.

The extension of the harvesting period is often accompanied by a reduction in the average diameter of the shoots and an increase in the proportion of substandard produce. P.J. Paschold *et al*. (2002) noted that in the second half of the long harvesting period, shoots are formed under conditions of limited carbohydrate resources, which leads to their lower weight and poorer organoleptic properties. Similar results were obtained by E. Collings *et al*. (2025), who found that extending the harvesting time under conditions of intensive production negatively affects the morphometric parameters and structural and mechanical properties (texture) of shoots. P.J. Paschold *et al*. (2002), M. Anastasiadi *et al*. (2019) proved that prolonged harvesting causes physiological stress in plants, which was manifested in a decrease in tissue turgor and accelerated ageing of shoots. This is especially important for the fresh produce market, where quality is a determining factor in competitiveness. Table 2 presents an evaluation of the morphometric and biochemical parameters of asparagus shoots, allowing a more detailed analysis of the effect of harvest duration on spear condition.

Table 2. *Dependence of the quality indicators of asparagus shoots on the duration of harvesting*

Indicator	4 weeks	6 weeks	8 weeks
Average diameter, mm	18.4	16.9	14.2
Share of marketable shoots, %	92.0	87.0	74.0
Sugar content in shoots, %	5.4	4.2	3.5

Source: data was summarised based on P.J. Paschold *et al.* (2002), H.Ya. Slobodianyk *et al.* (2015), A. Siomos (2018), V.B. Kutovenko *et al*. (2020)

The data presented in Table 2 indicate a significant influence of the duration of harvesting on the quality characteristics of asparagus shoots, which determine their commercial value and consumer properties. One of the main quality indicators is the average diameter of shoots, which is directly related to the alignment of marketable products and their compliance with market standards. During the four-week harvesting period, the average shoot diameter is 18.4 mm, which indicates the development of well-developed, aligned shoots with a high sales potential that meets the requirements of extra-class products (the highest grade). According to the researchers (Siomos, 2018; Nguyen *et al.*, 2024), extending the harvesting period to 6 weeks leads to a decrease in this indicator to 16.9 mm, and with an eight-week harvest – up to 14.2 mm, which indicates a gradual deterioration of biometric parameters due to the depletion of reserve carbohydrates of the rhizome. A decrease in the diameter of shoots with an increase in the duration of harvesting indicates a progressive depletion of the reserves of plastic substances of the rhizome. This indicator is one of the key criteria for product marketability, so its reduction is of significant economic importance (Fig. 4). The obtained generalisations confirm that excessive harvesting time negatively affects the commercial quality of asparagus shoots. Changes in the diameter of shoots are accompanied by a decrease in the share of marketable products. If during a short harvesting period the share of commercial shoots is 92%, then in six weeks it decreases to 87%, and in eight – up to 74%. This indicates an increase in the number of thin, uneven, or physiologically weakened shoots that do not meet the implementation standards. According to A. Zurawicz *et al*. (2008), W. Krzesinski *et al*. (2007), D. Kohli *et al*. (2023), simultaneously

with the decrease in marketability, there is a decrease in the sugar content in asparagus shoots from 5.4 to 3.5%, which negatively affects the consumer properties of shoots. K. Hanagasaki & S. Nakasone (2023) also showed that the sugar content of asparagus shoots decreases as the harvest season increases, as the shoots use the rhizome's carbohydrate stores for growth (Fig. 6).

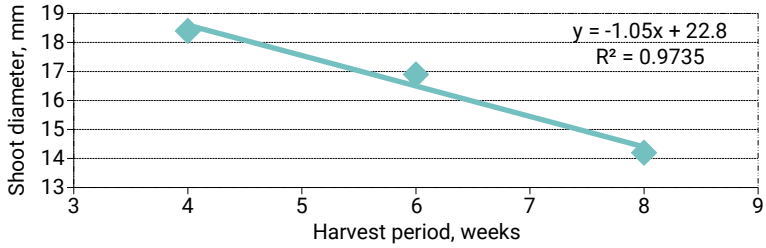

Figure 4. *Influence of harvesting time on the development of the diameter of asparagus shoots*

Source: developed by the author based on P.J. Paschold *et al.* (2002), H.Ya. Slobodianyk *et al.* (2015), A. Siomos (2018), V.B. Kutovenko *et al.* (2020)

Thus, the quality indicators are more sensitive to the duration of the harvesting period than the gross yield, and clearly reflect the degree of physiological load on asparagus plants. Comparison of the data in Tables 1 and 2 allows tracing the causal relationship between the growth of the number of shoots, a decrease in their average weight, and the deterioration of individual product quality indicators under extended harvesting conditions. In addition, Figure 5 shows the change in the average diameter of shoots depending on the duration of harvesting, which allows tracking the deterioration in the biometric parameters of the produce as the harvesting period is extended. The combined analysis of tabular and graphic materials allows forming a holistic understanding of the ratio of quantitative and qualitative indicators of the crop and serves as a basis for further discussion of the optimal parameters for harvesting asparagus shoots.

During the shortest harvesting period (4 weeks), shoots with the largest average diameter were formed, which indicates a sufficient level of providing growth processes with plastic substances. As the harvest increases to 6 weeks, there is a moderate but statistically significant decrease in the diameter of shoots, which is associated with a gradual decrease in the intensity of growth processes. The sharpest decrease in diameter is typical for the eight-week harvesting period. This indicates the depletion of reserve carbohydrates of the rhizome and a decrease in the potential for cell division and tissue stretching. In practical terms, this trend is extremely important, since it is the diameter of the shoots that determines their belonging to product classes and the possibility of implementation in the premium market segment. The aggregate analysis of Figure 1 and Figure 2 clearly demonstrates the relationship between quantitative and qualitative indicators of the crop: extending the harvest period increases the gross yield of products, but simultaneously reduces their commodity characteristics (Fig. 5). With the age of plantings, it is advisable to gradually reduce the duration of the harvesting season from eight to six weeks, which allows maintaining high marketability and a larger diameter of shoots. It is advisable to determine the optimal time to stop harvesting shoots by monitoring the content of soluble carbohydrates in the rhizomes. Monitoring of carbohydrate reserves in underground organs is the main tool for setting individual terms of termination of operation of each site. The criterion for ceasing the harvesting of shoots is a reduction in the soluble carbohydrate content to 10%, which ensures that

the plants remain viable for subsequent seasons. D.R. Wilson *et al.* (2002), A. Hamdi *et al.* (2023) suggest that if carbohydrate levels fall below this value, the plant will not have time to restore vegetative mass in the summer, which will lead to a sharp decrease in yields next year.

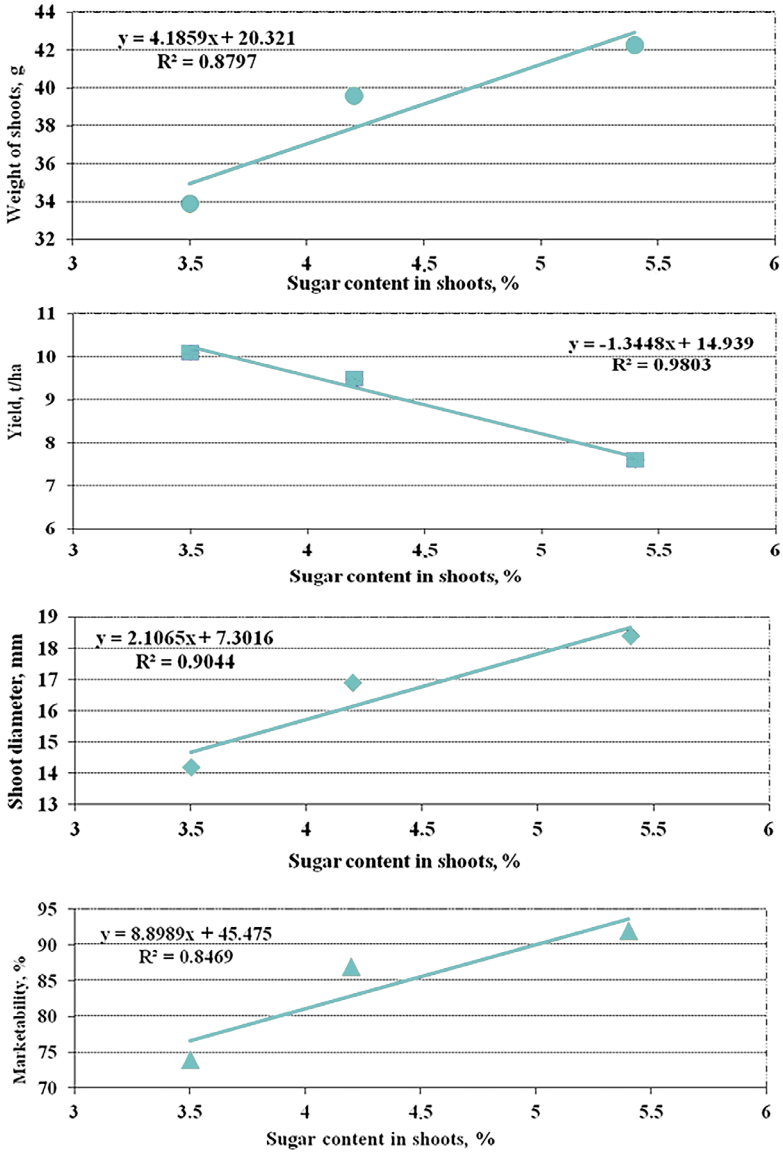

Figure 5. *Influence of sugar content in shoots on the technological parameters of asparagus*

Source: developed by the author based on P.K. Bhowmik & T. Matsui (2003), W. Krzesinski *et al.* (2007), A. Zurawicz *et al.* (2008), H.Ya. Slobodianyk *et al.* (2015), V.B. Kutovenko *et al.* (2020), A. Hamdi *et al.* (2023)

The physiological processes associated with shoot harvesting play an important role in the development of the asparagus crop. Each cut shoot is a direct loss of assimilation potential

and reserve substances. S. Shou *et al.* (2007) showed that once harvesting is complete, asparagus plants need sufficient time to restore their carbohydrate reserves. If the harvesting period is too long, reserve recovery becomes incomplete, which negatively affects bud initiation and shoot development in the following season (Bhowmik & Matsui, 2003; B. Santiago *et al.* 2021).

W.H. Elmer (2018) and K. Hanagasaki & S. Nakasone (2023) found that systematically extending the harvesting period leads to a gradual decline in the overall productivity of plantations and a reduction in their economically viable lifespan. When growing asparagus with an assimilating stem during the harvest period at the end of October, the plants had an average height of 102 cm, produced 12.5 stems, and the weight of the aboveground part is 22% higher, compared to plants of conventional technology (Slobodianyk *et al.*, 2015).

In the conditions of Ukraine, the issue of preserving the physiological stability of plants is particularly relevant. Limiting the duration of harvesting allows plants to move faster to the assimilation phase and accumulate carbohydrates more efficiently. The findings of V.B. Kutovenko *et al.* (2020), T.V. Ivchenko *et al.* (2025) confirmed that adapting harvesting regimes to local conditions is a key condition for obtaining stable yields of high quality. The introduction of scientifically based terms and duration of harvesting will help to increase the profitability of asparagus production in Ukraine.

The duration of harvesting affects the durability of plantings. There is a direct relationship between the duration of the harvesting season and the period of productive operation of the plantation. Studies show that harvesting shoots for more than 8 weeks during the season depletes the carbohydrate reserves in the rhizome. In the 9th year of such operation, the yield falls by 23-36% compared to the control areas, where harvesting lasted 6 weeks. Thus, the intensive use of plantations within a shorter production cycle (8-10 years) represents a more economically advantageous strategy than moderate use over 15-20 years, as it enables faster return on investment and timely crop rotation to improve the phytosanitary status of the soil. The dynamics of yield and economic suitability of asparagus plantations over the years of vegetation are shown in Table 3, which shows the life cycle of industrial asparagus plantations under intensive cultivation technology.

Table 3. *Yield and quality of asparagus shoots depending on the age of the plantation*

Growing season	Life cycle stage	Yield, t/ha	Yield of class 1 shoots (>16 mm), %	Profitability
1-2	Plantation establishment and plant adaptation	0	0	Negative (investment)
3	Start of industrial harvest	1.5-2.5	90-95	Low
4	Beginning of maximum fruiting	4.0-5.5	85-90	Average
5-7	Peak performance	6.0-9.5	80-85	Maximum
8	Period of stable performance	5.5-7.0	70-75	High
9	Reduced performance	4.5-5.5	55-60	Average
10	Profitability threshold	3.5-4.5	40-45	Low (payback threshold)
11-12	Physiological exhaustion	2.5-3.5	25-30	Negative

Source: developed by the author based on D.R. Wilson *et al.* (2002), H.Ya. Slobodianyk *et al.* (2015), D. Drost (2020)

According to Table 3, the dynamics of asparagus yield is parabolic. The period from the 4th to the 7th years of vegetation is defined as the phase of maximum biological and economic impact. At this time, the rhizome has the largest volume of storage tissue capable of accumulating nutrients in an amount sufficient for the development of class 1 shoots. However, starting from the 8th year,

there is a gradual decrease in yield, which in the scientific literature is associated with the accumulation of toxic root secretions and soil pathogens.

Research conducted by D. Drost (2023), confirmed that in the 10th year of operation of plantings, the overall yield may remain relatively high, but the qualitative composition undergoes negative changes: the share of class 1 shoots falls below 50%. The critical period is the 10th year of vegetation. As noted by D. Drost (2020), in its review of the physiology of perennial crops, after a decade of continuous cultivation, the cost of manually harvesting and sorting small shoots (classes 2 and 3) begins to exceed the revenue from their sale. In the industrial conditions of Europe and North America, this indicator is a signal for the elimination of the plantation. In the conditions of contemporary agribusiness, it is more profitable to renovate plantings after 10 years than to try to maintain low-productive plantations. This also allows avoiding critical contamination of the soil with fusarium, which is important for further crop rotation or fruit change.

According to the conclusions of P.J. Paschold *et al.* (2002), extending the life span to 12-15 years leads to the fact that plants become too vulnerable to stressors and diseases, which makes protecting such plantings economically unjustified. In addition, on old plantations, weed control is significantly more difficult due to the risk of mechanical damage to plant rhizomes, which further reduces the profitability of production by 25-30%. Given this, the ageing of the root system and the weakening of carbohydrate metabolism after a ten-year growing cycle become critical factors that require the renewal of production plantings.

Conclusions

The study investigated the influence of the duration of harvesting asparagus shoots on the yield, quality indicators of products, and long-term productivity of plantings. The purpose of the study was to establish the optimal duration of the harvesting period, considering the physiological state of plants and the economic efficiency of production. The analysis carried out suggests that the objective set has been achieved. It was found that the duration of harvesting asparagus shoots is one of the main factors determining the yield, product quality, and long-term productivity of plantings, since it directly affects the balance between the use of reserve carbohydrates and the restoration of the physiological potential of plants. The results of the study showed that extending the harvesting period from 4 to 8 weeks contributes to an increase in overall yield by increasing the number of shoots. Such data indicate a gradual decrease in the average weight of shoots and a deterioration in their commercial characteristics. Analysis of the results obtained established a nonlinear nature of the relationship between the duration of harvesting and yield, which indicates a limited biological potential of the crop. The analysis revealed that extending the harvesting period excessively leads to the depletion of rhizomes and a reduction in carbohydrate reserves. The results obtained suggest that this negatively affects the productivity of plantings in subsequent years. In addition, it was found that the quality indicators of shoots, in particular, their diameter, the proportion of marketable products, and the sugar content, respond more sensitively to changes in the duration of harvesting than the total yield.

Summarising the results obtained, it can be noted that effective management of the duration of harvesting should be based on the physiological state of plants and the balance between the use of reserve carbohydrates and their recovery. The analysis showed that excessive intensification of harvesting without considering these processes leads to a decrease in the long-term productivity of plantings. Conceptually, the above indicates the need to optimise technological approaches to growing asparagus based on the biological limitations of the crop. This may indicate that product quality indicators are more informative indicators of the state of plantings than yield indicators alone. It was also found that physiological depletion of rhizomes and a decrease in the ability to accumulate carbohydrates after 8-10 years of vegetation determine the natural limits

of effective operation of plantings. Prospects for future research include refining the optimal harvesting duration across different soil and climatic conditions, investigating varietal differences in asparagus response to harvest intensity, and conducting a more detailed analysis of the physiological mechanisms underlying the restoration of plant carbohydrate balance.

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Conflict of Interest

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Теоретичні основи формування врожайності та якості пагонів спаржі залежно від тривалості збирання

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Анотація. Актуальність дослідження зумовлена зростанням попиту на спаржу та необхідністю підвищення ефективності її вирощування в умовах України з урахуванням біологічних особливостей культури та економічних чинників виробництва. Метою роботи є теоретичне обґрунтування впливу тривалості збирання пагонів спаржі на формування врожайності, біометричних і якісних показників продукції, а також довговічність насаджень. У роботі використано методи аналізу, узагальнення та систематизації результатів сучасних національних та міжнародних наукових досліджень, зосереджених на фізіології росту рослин спаржі, технології вирощування та регуляції процесів відновлення асиміляційного апарату рослин. Було досліджено взаємозв'язок між тривалістю періоду збирання пагонів і продуктивністю рослин, а також процесами накопичення запасних поживних речовин у кореневищах. Виявлено, що тривале збирання врожаю спричиняє виснаження рослин і знижує їх здатність до відновлення асиміляційного апарату після завершення збору. Було встановлено, що надмірне подовження періоду збирання призводить до зменшення діаметра пагонів, зниження їх товарності та погіршення якісних характеристик продукції. Водночас визначено, що оптимально обмежена тривалість збирання сприяє стабільному формуванню врожаю та забезпечує високі показники якості пагонів. Було проаналізовано фізіологічні та економічні аспекти використання насаджень і встановлено, що ефективна експлуатація плантацій обмежується 8-10 роками внаслідок морфофізіологічного старіння кореневої системи та

порушення вуглеводного обміну. Узагальнено, що регулювання тривалості збирання є ключовим елементом технології вирощування спаржі. Практична цінність роботи полягає у можливості використання отриманих результатів агровиробниками, фермерськими господарствами та науковими установами для оптимізації технологій вирощування спаржі в умовах України

Ключові слова: спаржа лікарська; пагони; вуглеводи; продуктивність рослин; біометричні показники; якість продукції