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ФУНКЦІОНАЛЬНА РОЛЬ ПОДІЛЬНИКІВ ПІД ЧАС ЗБОРУ ПОЛЕГЛОГО ЛЬОНУ

Полеглість – одна з критичних проблем під час збирання льону. Функціональна роль подільників у системах збирання льону-довгунця достатньо повно висвітлена в класичній і сучасній технічній літературі. Водночас питання їх застосування під час збирання сучасних сортів олійного льону залишаються недостатньо дослідженими. Підвищені показники висоти та густоти рослин олійного льону формують поведінку стеблостою, подібну до поведінки полеглого льону-довгунця. У статті наведено аналітичну оцінку конструкцій подільників, виконану на основі синтезу результатів сучасних інженерних досліджень і технічної документації виробників льонозбиральних машин. Оглянуто механізми розділення стебел, дію підйомних сил та формування контрольованого попереднього нахилу, щоб з'ясувати, як подільники впливають на стабільність подачі та якість збирання. Особливу увагу приділено порівнянню жорстких і пружинних подільників та визначенню їх ефективності за різних рівнів полеглості. Аналіз показує, що подільники суттєво підвищують повноту захоплення стебел, зменшують пошкодження, спричинені згинанням, і стабілізують потік стебел не лише під час витягування льону-довгунця, а й під час зрізання льону олійного. Розроблено конструктивні рекомендації щодо інтеграції подільників у сучасні льонозбиральні машини, зокрема оптимізації висоти встановлення, застосування гнучкого кріплення, раціональної кривизни носової частини та поверхонь із низьким коефіцієнтом тертя. Отримані результати підкреслюють, що подільники слід розглядати як невід'ємний функціональний компонент під час збирання обох категорій льону, оскільки вони безпосередньо впливають на ефективність роботи машини, рівномірність формування стрічок та збереження якості матеріалу.

Ключові слова: *збирання льону; льон полеглий; подільник; льон-довгунець; льон олійний; відділення стебел; нахил стебла; механічна взаємодія.*

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FUNCTIONAL ROLE OF DIVIDERS IN HARVESTING LODGED FLAX

Lodged flax remains one of the most critical challenges in mechanized harvesting due to stem interlocking, ground-level deformation, and the high elasticity of flax stems. While the functional role of crop dividers in fiber flax pulling systems is well described in classical literature, little attention has been paid to their applicability in harvesting modern oilseed flax, whose increasing plant height and density lead to stem-flow behaviour similar to lodged fiber flax. This paper presents an analytical evaluation of divider designs, synthesizing findings from recent engineering studies and technical documentation. The mechanisms of stem separation, lifting forces, and controlled pre-bending are examined to clarify how divider affect feeding stability and harvesting quality. Particular emphasis is placed on comparing rigid and spring-loaded dividers and identifying their performance under varying lodging conditions. The analysis demonstrates that dividers significantly improve the completeness of stem capture, reduce bending-induced damage, and stabilize crop flow not only in fiber flax pulling but also in cutting-based oilseed flax systems. Design implications are formulated to guide the integration of divider into modern flax harvesters, including adjustable height settings, flexible mounting, optimized nose curvature, and low-friction surfaces. The findings highlight that crop dividers should be considered a functional component for both flax categories, with direct impact on harvesting efficiency, ribbon uniformity, and material preservation.

Keywords: *Flax harvesting; Lodged flax; Crop divider; Fiber flax; Oilseed flax; Stem separation; Stem bending; Mechanical interaction;*

Introduction. Flax (Linum usitatissimum L.) is a historically important crop grown for fiber and seed [1]. Unlike most grain crops, fiber flax is harvested by pulling the entire plant (including roots) from the soil rather than cutting [2]. This preserves the full length of the stem for maximum fiber yield. Flaxseed is harvested using flax harvesters or separation technology, but the stems are cut [3]. A critical component of mechanized flax pulling harvesters is the crop divider – a wedge-like guiding device at the front of the harvester. The divider's role is to separate standing flax plants into manageable strips and guide them into the pulling mechanism of the machine [3].

However, flax is a slender, elastic and tall crop, with fiber varieties reaching 0.9–1.2 m height [4, 5] and exceptionally high elastic and slenderness ratios [4]. This makes flax prone to lodging – bending or falling over due to wind, rain, or dense sowing [6]. Lodged (flattened or severely inclined) flax presents a major challenge during harvesting. The divider must lift and part tangled, leaning stems without excessive losses or fiber damage. [6, 7] Modern engineering research, much of it from flax-growing regions of Eastern Europe (e.g. the western regions of Ukraine), has focused on improving divider [8].

This paper reviews modern types of flax crop dividers and evaluates which designs perform most effectively under lodging conditions. We examine the stem separation process by the divider, the forces acting on flax stems, and how stem length and inclination angle affect harvest quality.

Analysis of recent studies. The harvesting methods differ between the two types of the flax (fiber and oilseed) due to the distinct agronomic and morphological characteristics of the plants. Fiber flax requires pulling the entire plant from the ground, preserving the full stem for fiber extraction. This is typically done using specialized flax pulling machines (fig. 1). [2, 11] In contrast, oilseed flax is generally harvested by cutting the stems using conventional combine harvesters or specially adapted mechanisms [3].

Fig. 1. **The Flax double rows pulling machine. Illustration provided by source [2]**

While there is a broad body of literature and technical development focused on dividers for fiber flax harvesters, there is a noticeable lack of unified classification or comparative evaluation of different divider types across both flax categories. Previous studies by Dai et al. [3] and Mańkowski et al. [7] have detailed designs for dividers in fiber flax pulling systems. Similarly, Didukh et al. [2] investigated mechanical solutions for pulling oleaginous flax but did not elaborate on divider configuration. This fragmentation creates an opportunity for holistic analysis of crop divider function and design in flax harvesting.

Additionally, most existing studies focus on the operational dynamics of dividers for a specific flax type, without drawing broader design principles or universal recommendations. For example, research has shown that the geometry and positioning of the divider influence how the stems enter the pulling unit – which directly affects pulling purity, fiber alignment, and overall harvest quality [8, 10]. However, few studies attempt to provide a unified typology of flax dividers or systematically compares their suitability for varying field conditions and flax varieties.

Moreover, with current trends towards mechanizing oilseed flax harvesting and improving the fiber potential of linseed stems, there is a growing need to incorporate divider technologies into machines used for oleaginous flax. High-density sowing and improved varietal height have made the oilseed flax crop more susceptible to overlapping and irregular feeding, even in standing crops. Despite this, dividers are rarely integrated into combines used for linseed, partly due to the assumption that cutting eliminates the need for guided feeding. However, recent engineering analyses suggest that stem orientation and guidance remain important even during cutting, especially to ensure uniform swathing, reduce fiber entanglement, and prevent reel blockage [9].

Table 1.

Comparison of flax divider types

Divider Type	Design Features	Performance in Lodged Flax
Rigid bar divider	Long steel wedge bar with fixed mounting; bent upward tip; often has skid plate for ground contact.	Can part standing crop well, but tends to push or ride over severely lodged stems. High resistance in downed crop can cause missed stems or tangling. Less forgiving over obstacles, so lodged patches may reduce reliability.
Spring-loaded divider	Wedge bar with spring-loaded or pivoting attachment to frame. Tip (toe) can move upward when resistance is encountered, then return. Height often adjustable.	Much better adaptation to lodged or uneven crop. Divider “floats” to maintain contact, lifting fallen stems gently. Reduces risk of bulldozing lodged plants and improves reliability when harvesting lodged flax. Helps ensure more complete gathering of low-lying stems with less fiber damage.

From an engineering standpoint, crop dividers are responsible for three main functions: 1. Isolating a band of stems corresponding to the width of the pulling or cutting mechanism. 2. Pre-aligning or inclining the stems in a manner that facilitates smooth entry into the harvesting zone. 3. Minimizing resistance and losses by reducing tangling, overlapping, or stem breakage at the machine's entry point.

When used with fiber flax, dividers ensure stems remain intact and properly aligned for downstream processing, such as retting and scutching. For oilseed flax, dividers could assist in reducing losses by guiding stems consistently into the cutter bar and maintaining a cleaner swath for post-harvest seed separation or potential fiber extraction. Research shows that the consistency of stem orientation directly correlates with the efficiency of harvesting belts or reel-cutter interaction [3, 9].

Given the importance of these processes, and in light of the limited cross-type studies, the present work aims to fill this research gap. The goal is to provide a comprehensive analysis of divider design and operation for flax harvesting under varied agronomic conditions. This involves studying both fiber and oilseed flax and exploring their shared requirements for crop feeding into the harvesting apparatus. This is especially relevant for regions such as Western Ukraine, where both types of flax are cultivated and advanced harvesting techniques are under development.

The aim of this analytical study is to evaluate the functional suitability of different types of flax crop dividers under conditions of lodged and uneven stands, and to identify the key engineering factors that influence stem separation, lifting efficiency, and feeding quality during harvesting.

The study also aims to generalize the operational principles of dividers for both fiber and oilseed flax and to determine which geometrical and mechanical characteristics of dividers most significantly affect harvesting quality, completeness of picking, and the preservation of stem integrity.

Materials and Methods. This study is analytical in nature and is based on a structured review and synthesis of scientific, technical, and engineering sources related to flax harvesting mechanisms. The material for analysis includes peer-reviewed research articles published between 2015 and 2025 [2-4, 7-10], patents on pulling and dividing devices [12-16], operational documentation for flax harvesters, and technical manuals describing divider configurations [6, 7, 11]. Special attention was given to studies examining -stem–divider interaction, lodged crop behaviour, and the influence of divider geometry on the feeding quality of both fiber and oilseed flax.

The methodological approach involves comparative evaluation of the two dominant categories of flax crop dividers – rigid bar dividers and spring-loaded or floating dividers. It based on their structural characteristics, adaptability to uneven or lodged crops, and their documented impact on stem lifting, separation quality, and the completeness of feeding into the pulling or cutting mechanism. The analysis incorporates engineering criteria such as divider height, nose curvature, side-rod geometry, and the kinematic relationship between the divider and the forward motion of the harvester.

To clarify how the divider influences harvesting quality, the process of stem separation was examined through functional descriptions available in the literature and technical documentation. These sources provide information on the forces acting on stems as they pass through the divider zone, including lateral bending forces, lifting forces, frictional interactions, and the transitional tensile forces applied by pulling belts or disk-belt mechanisms. The evaluation focuses on understanding how stem length, lodging angle, crop density, and divider positioning contribute to successful stem isolation, lifting, and feeding continuity.

The study employs synthesis of reported engineering findings, qualitative comparison of device designs, and interpretation of agrotechnical recommendations regarding acceptable harvesting losses, stem stretching, and ribbon alignment. This integrative analytical method allows the identification of the most influential factors determining the performance and suitability of different divider types under lodged flax conditions, and enables formulation of generalized principles applicable to harvesting both fiber and oilseed flax.

Results. As the flax (fiber flax) harvester advances, the divider initiates the harvesting process by isolating a defined strip of flax stems and guiding it toward the pulling apparatus. This interaction can be described as a sequence of functional stages (Fig. 2).

1. Entry of stems. The pointed nose of the divider penetrates the flax stand, while the lower rod or skid operates at ground level or near the crop base. Side rods extend upward and backward, forming a wedge-shaped structure that separates the standing crop into discrete strips corresponding to the width of the pulling mechanism. As a result, the flax stand is divided into parallel bands, each directed into the intake zone between converging pulling belts or between a belt and a disk.

2. Initial separation and controlled inclination. As stems come into contact with the side rods of the divider, they are displaced laterally and begin to incline relative to their original upright position. This inclination is induced by the divider geometry and forward motion of the machine. Stems directly contacted by the divider are guided outward or toward the pulling throat, while central stems within the strip also incline due to mechanical interaction and entanglement with neighboring plants. When properly adjusted in terms of height, angle, and spacing, the divider produces a controlled pre-inclination of the entire stem group, which facilitates smoother entry into the pulling zone and reduces excessive bending during subsequent gripping.

3. Clamping and pulling. Once the separated and pre-oriented strip reaches the pulling apparatus, the stems are clamped and uprooted. In conventional systems, converging rubber belts grip the stems, whereas more recent designs employ a belt–disk combination in which a rotating disk presses the stems against a moving belt. In both configurations, the stems are securely clamped and conveyed upward and backward as the harvester advances, resulting in their extraction from the soil. At this stage, the divider has completed its primary function by ensuring orderly delivery of stems to the pulling mechanism.

4. Merging and laying. Following uprooting, multiple streams of flax from adjacent pulling sections are combined into a single flow. The belts typically converge downstream of the pulling zone, merging the plant streams before transferring them to the rear of the machine. A transverse conveyor or laying mechanism then deposits the stems onto the field as a uniform ribbon suitable for drying and retting. The quality of this ribbon depends strongly on the initial separation performed by the divider; inadequate strip formation may lead to stem crossing, uneven ribbon thickness, or overlapping swaths, adversely affecting retting uniformity and fiber quality.

Throughout this process, the forces on the flax stems change in nature: Initially, at the divider, stems experience lateral bending forces and friction; later, the pulling apparatus applies tensile force (vertical pulling) to uproot them. Let's examine the forces at the divider stage in more detail.

During the stem-dividing process, flax stems are subjected to a combination of lateral, lifting, frictional, and inertial forces, the interaction of which determines the effectiveness of stem separation under lodged conditions. The lateral force generated by the divider rod induces stem bending and initiates separation of interlocked stalks. Its magnitude is governed by divider geometry, surface characteristics, and forward speed; smooth profiles and low-friction surfaces promote stem sliding and reduce resistance, whereas blunt or poorly aligned dividers increase bending stress and the risk of stem damage. Such effects are particularly pronounced in lodged flax, where stems tend to ride along the divider surface before entering the pulling or cutting zone [3, 7, 10].

An upward force component arises from the combined effect of divider inclination, nose curvature, and forward motion of the harvester. Although typically smaller than the lateral force, this lifting action is critical for raising flat-lying stems and enabling their engagement with the pulling or cutting mechanism. Passive lifting through wedge-shaped or curved divider elements is the prevailing solution in flax harvesters, contrasting with active lifting systems used in other crops. Under severe lodging, increased stem mass and moisture intensify gravitational resistance, requiring more effective geometric lifting rather than increased forward speed [7, 9].

In addition to bending and lifting forces, lodged flax presents substantial drag and inertial resistance due to stem entanglement and soil contact. When divider geometry or operating speed is suboptimal, stems may be displaced as a compact mass rather than being cleanly separated, leading to unstable feeding and uneven harvesting. Studies indicate that, in such conditions, a portion of the pulling effort is effectively transferred to the traction force of the machine, particularly when stems are inclined relative to the pulling direction [2, 8, 10].

Overall, the divider governs the redistribution of forces acting on lodged flax by converting excessive bending and drag into controlled stem inclination prior to tensile loading by the pulling or cutting apparatus. Modern flexible or spring-loaded divider designs mitigate force peaks by yielding under resistance, thereby reducing stem breakage, fiber damage, and feeding interruptions. Effective divider design therefore relies on balancing lateral separation, passive lifting, and friction control to ensure stable stem flow with minimal mechanical stress [7, 9].

The quality of flax harvesting is strongly influenced by stem length and the angle at which stems enter the harvesting apparatus, particularly under lodged conditions. In this context, harvesting quality is assessed through several interrelated indicators, including picking completeness, the extent of stem damage, and the uniformity of the formed flax ribbon. Lodging severity is directly associated with reduced stem inclination relative to the horizontal plane, while excessive stem length increases the likelihood of lodging and complicates controlled feeding into the header (Table 2).

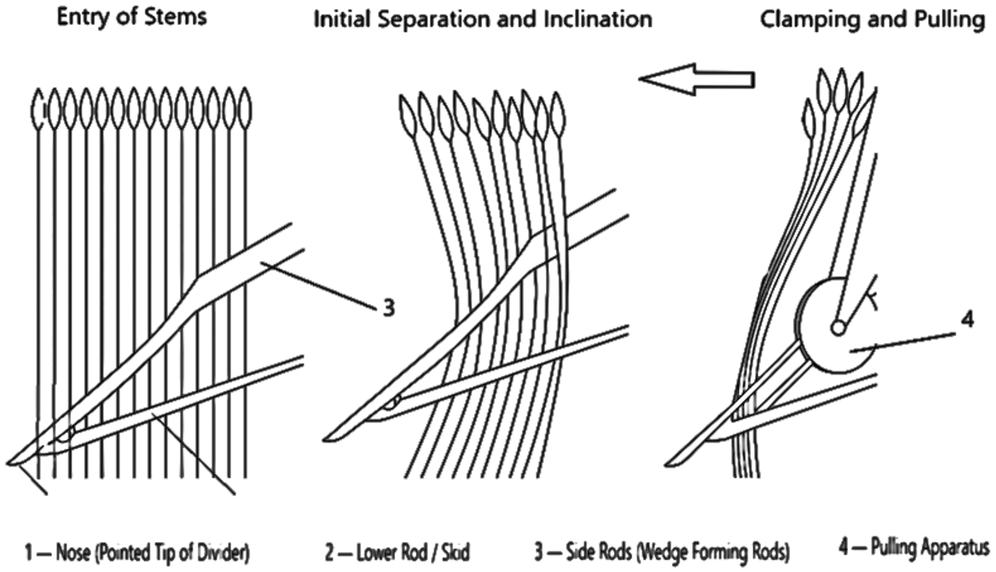

Fig. 2. **Stages of Stem Separation by the Divider. Illustration provided by author**

Under optimal conditions, upright flax stands with stem lengths of approximately 0.8–1.5 m allow harvesting systems to achieve near-complete picking efficiency, typically exceeding 99%. However, lodging significantly alters stem orientation and accessibility. When stems lie close to the ground or are inclined opposite to the direction of travel, the effectiveness of stem capture decreases, and acceptable picking purity may drop to around 95%. Missed stems are predominantly those that remain below the effective operating zone of the divider or are insufficiently separated prior to entering the pulling or cutting mechanism. Short lodged stems (<0.5 m) are particularly challenging, as they may escape divider contact or fail to be securely engaged by pulling belts, necessitating careful adjustment of divider height and operating direction.

Table 2.

Key harvesting quality parameters for flax (fiber and oilseed) under upright and lodged conditions

Parameter	Typical value / threshold	Practical implication	Source
Stem length (upright flax)	0.8–1.5 m	Enables high picking completeness	[7]
Stem length (short lodged flax)	<0.5 m	Increased risk of missed stems	[2,10]
Picking completeness (upright)	≥99%	Optimal harvesting quality	[7]
Picking completeness (lodged)	≈95%	Acceptable losses under lodging	[7,10]
Maximum allowable stem stretch	≤1.2× (20%)	Preserves fiber integrity	[2,8]
Allowable ribbon skew angle	≤20°	Prevents ribbon entanglement	[7,10]
Critical lodging angle	30–40°	Cutter bar alone becomes ineffective	[6,9]

Lodging also increases the risk of mechanical damage to stems and fibers. Long flax stems subjected to pulling at shallow angles experience increased bending and tensile deformation. Excessive longitudinal stretching, exceeding approximately 20% of stem length, is generally associated with fiber slippage, partial breakage, or surface damage, which negatively affects fiber quality and seed retention. Moreover, uneven stem orientation during feeding can result in skewed alignment within the flax ribbon. While a misalignment angle of up to 20° is typically acceptable, larger deviations promote ribbon entanglement and irregular deposition on the field. These effects are exacerbated when divider geometry or positioning does not adequately account for stem length and lodging angle.

The uniformity of the laid flax ribbon represents a further critical quality criterion, as it directly influences subsequent retting processes. Uneven feeding caused by lodging may produce ribbons with gaps, overlaps, or localized bunching. Engineering and agrotechnical guidelines therefore emphasize the formation of straight, continuous ribbons with minimal skew and consistent thickness, conditions that are difficult to achieve without effective stem guidance.

Recent engineering studies consistently identify the divider as a decisive element governing feeding stability, pulling continuity, and stem integrity in fiber flax harvesting. Experimental and analytical investigations have shown that dividers not only separate crop strips but also induce controlled pre-orientation of stems, ensuring smooth entry into belt or disk-belt pulling systems [2, 7, 10]. In the absence of such guided pre-alignment, long and elastic flax stems tend to cross, twist, or bypass the pulling zone, resulting in reduced picking purity and increased mechanical damage.

Although these findings were originally established for fiber flax, they are increasingly applicable to modern oilseed flax. Intensified cultivation practices aimed at maximizing seed yield have led to higher plant densities and increased stem height, causing oilseed flax to exhibit mechanical behavior comparable to lodged fiber flax. Under such conditions, stems interlock, resist separation, and enter the cutting zone at inconsistent angles, reproducing the same mechanical challenges observed in pulling-based systems [6, 9]. Consequently, effective harvesting requires not only cutting action but also controlled stem orientation prior to engagement with the working organs.

In oilseed flax harvesting, the absence of a divider often results in uneven cutter-bar loading, incomplete capture of low-lying stems, elevated seed losses due to repeated reel impact, and irregular swath formation. Published field observations indicate that when lodging angles exceed approximately 30–40°, the cutter bar alone is insufficient to lift and guide stems, leading to accumulation and non-uniform flow at the header [6, 9]. Therefore, the engineering principles underlying divider use in fiber flax – stabilizing stem flow, lifting low-lying plants, reducing resistance, and preventing entanglement – are directly transferable to oilseed flax harvesting. Recent developments in oilseed flax machinery, including prototypes from Chinese manufacturers (Fig. 3), confirm a growing tendency to integrate divider-like guiding elements into cutting-based harvesting systems, reflecting their recognized role in improving crop engagement and harvesting quality [9, 16].

Fig. 3. **Example of a modern tracked-type flax harvester developed in China, equipped with guiding elements that perform divider functions. Illustration provided by source [9] and manufacturer open-access materials**

Based on the synthesis of mechanical interaction principles, divider configurations, and lodging-related stem behavior, the following design implications can be formulated for both fiber and oilseed flax harvesting systems (Table 3).

In summary, the analysis of lodged fiber flax demonstrates that stem inclination, interlocking, and ground-level deformation fundamentally disrupt the harvesting flow unless the stems are separated and lifted prior to entering the pulling or cutting mechanism. Across multiple studies, the divider consistently appears as the component that restores order to the flow by reducing lateral resistance, initiating controlled stem inclination, and ensuring that even low-lying plants are captured.

Table 3.

Design Implications for Crop Divider Application in Fiber and Oilseed Flax Harvesting

Design Implication	Engineering Rationale	Relevance for Fiber Flax	Relevance for Oilseed Flax
Low divider height near soil level	Ensures capture of low-lying stems; prevents stems from slipping under the divider	Critical for lodged fiber flax due to long, flexible stems	Necessary for tall, dense modern oilseed flax prone to lodging
Spring-loaded / floating mounting	Reduces peak forces, adapts to uneven terrain, prevents bulldozing	Maximizes picking completeness in lodged stands	Stabilizes cutter-bar feeding and reduces seed loss
Moderate upward nose curvature	Generates a lifting vector; avoids excessive bending	Prevents fiber damage; improves orientation before pulling	Ensures uniform feeding into cutter bar in lodged conditions
Smooth tapering of side rods	Controls gradual stem inclination; reduces resistance	Maintains stable stem flow into belts/disks	Reduces bunching and reel overload
Passive guiding elements for cutting-based systems	Compensates for lack of pulling mechanism; aligns stems.	Optional but beneficial under severe lodging	Strongly recommended for modern oilseed flax combines
Divider selection by lodging severity	Matches mechanical behavior to field conditions	Flexible dividers required at lodging >30–40°	Same threshold applies; cutter bar alone insufficient
Universal adjustable divider for dual-purpose harvesters	Increases machine versatility; reduces need for header changes	Applicable when harvesting mixed flax varieties	Supports oilseed harvesting with varying stem density
Low-friction contact surfaces	Minimizes snagging and surface abrasion	Preserves fiber quality	Reduces boll loss and stem tearing

These findings are directly applicable to oilseed flax harvesting, as contemporary agronomic practices increasingly result in denser stands and greater average stem height than those typical of traditional oilseed flax production. Under lodging conditions, such stands exhibit mechanical behavior analogous to fiber flax, characterized by stem interlocking, low entry angles relative to the header, and increased resistance to separation at ground level. In the absence of a guiding element at the header front, oilseed flax stems tend to enter the cutting zone irregularly, leading to incomplete stem capture, uneven loading of the cutter bar, increased seed loss due to repeated reel impact, and non-uniform swath formation [3, 9, 16]. Consequently, the functional role of the divider extends beyond pulling-based systems: by stabilizing stem flow, promoting controlled pre-orientation, and mitigating the mechanical effects of lodging, dividers become a critical component in reducing harvesting losses and ensuring consistent feeding in cutting-based oilseed flax harvesters.

Conclusions. This analytical study clarifies the functional role of crop dividers as a key interface between lodged flax stems and harvesting mechanisms. By synthesizing recent engineering studies, technical documentation, and patent-based solutions, the paper demonstrates that dividers are not auxiliary components but critical elements governing stem separation, lifting, and flow stabilization prior to pulling or cutting.

The analysis shows that under lodged conditions the divider redistributes mechanical loads acting on flax stems by converting excessive bending and drag into controlled stem inclination before tensile loading occurs. Lateral forces initiate separation of interlocked stems, while passive lifting generated by divider geometry enables engagement of flat-lying plants with the harvesting apparatus. In such conditions, divider design directly affects harvesting completeness, feeding stability, and the risk of stem damage.

A comparative evaluation of rigid and spring-loaded divider configurations indicates that flexible or floating designs provide superior adaptability to uneven terrain and severe lodging. Their ability to yield under resistance mitigates force peaks, reduces bulldozing of lodged stems, and minimizes stress concentrations that can lead to fiber breakage or uneven uprooting.

Although divider applications have traditionally been associated with fiber flax pulling systems, this study demonstrates that the same functional principles are increasingly relevant for modern oilseed flax harvesting. Increased plant height and stand density cause oilseed flax to exhibit mechanical behavior similar to lodged fiber flax, making controlled stem guidance essential even in cutting-based systems. Recent machinery concepts and patented solutions confirm a technological shift toward integrating divider or divider-like guiding elements into oilseed flax harvesters.

The main contribution of this work lies in formulating design implications that link divider geometry, mounting elasticity, and operating conditions to the mechanical behavior of lodged flax. These implications provide a structured framework for selecting and adapting divider designs for both fiber and oilseed flax harvesting. Future research should focus on quantitative validation of these relationships through field experiments and numerical modeling to refine divider parameters under varying lodging scenarios.

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