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STUDIES OF THE PROCESS OF LEVELLING OF RICE MASS IN FEEDERHOUSE OF A COMBINE HARVESTER

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Uneven distribution of rice mass fed into a threshing apparatus is one of the main causes of downgraded performance of a combine harvester during rice harvesting. One of the possible solutions is fitting V-shaped corrugation profiles at varying intervals on the bottom of the feederhouse. Intervals between the corrugations are smaller at the entry part of the feederhouse than at the end. This ensures smoother and more even distribution of flow of high-yield (above 5 t/ha), higher humidity (over 30%) and entangled biomass of rice along the width of feederhouse and, consequently, along the width of threshing apparatus.

Our studies have shown that the levelling ratio depends on the amount of the rice mass fed into the feederhouse. The presented dependences support the sensitivity of the levelling tool to overloads. For example, increasing the feed rate of rice biomass from 3.4 kg/s to 5.5 kg/s results in the increase of the levelling ratio from 43% to 67%, where the levelling tool is not used; and from 62% to 75%, where the work tool is used. The levelling ratio is also influenced by physical-mechanical properties of rice, as well as its humidity. In case of increase of humidity from 20% to 55%, i.e. 2.8 times, the levelling ratio has increased from 53% to 70%, or 1.3 times, where the levelling tool has been used; and from 42% to 54%, or 1.2 times, where the levelling tool is not used. The levelling ratio of rice mass is considerably less dependent on humidity than on the feed rate.

Combine harvester, rice, feederhouse, harvesting method, corrugations.

Introduction

Relevance of the study. Rice is one of the most valuable high-yield grain crops in the world. Rice production is among the priority tasks for ensuring food security. Rice crops currently account for over 74 thousands of hectares in the Republic of Kazakhstan. Rice harvest exceeded 360 thousand tons in 2013. Average yield of rice was 4.86 t/ha. The experience of Kazakhstan has shown that growth in rice production is possible only if measures for increasing the crop yield are taken along with measures of the reduction of grain loss and prevention of quality loss during harvesting and processing. Harvesting is the most important period of rice cultivation process. Plant lodging, uneven maturity before harvesting and drying in interrupted windrows of different thickness and width lead to considerable (up to 25%) loss of rice during harvesting [Zhetpeisov, 2010]. Harvesting is the most labour intensive stage of rice cultivation. Rice is harvested either manually or with the most primitive tools in many countries worldwide. This is related not only to physical-mechanical properties of rice (stalks may often grow higher than 2 m) and small areas of rice bays (30×100 m), but also to lower loss of grain. According to the available data, loss of rice during machine-assisted harvesting is 4.7 times higher than during manual harvesting. On the other hand, manual harvesting requires more time, which also entails certain loss of grain. Machine harvesting is currently the mainstream harvesting method in all the rice growing countries [Zhetpeisov, 2006].

Specific properties characteristic of rice only (compared to spiked cereals) shall be taken into account when planning the harvesting works, such as high humidity of rice grain and stalk, considerable logging and almost twofold (compared to wheat) stalk rupture force, high soil humidity in the rice paddies, small area of paddy fields and track length. Rice is the most expensive crop among all other cereal crops. As a result, mechanical damage during threshing should be avoided as much as possible. Rice kernel is typically very brittle and considerably less fracture-resistant than wheat, rye, maize or barley. This may be due to the conditions of cultivation and high starch content in a rice kernel with very small grains. Internal fissuring is another distincitive property of rice kernel. Moisture content of the surface layers of kernel is lower than that of the central layers, meaning that, when exposed to sunlight, surface layers tend to shrink to a greater extent than the central layers. This results in fissuring, which may increase progressively as long as the rice is not harvested after complete maturation [Pugachev, 1981].

Rice grown in the Republic of Kazakhstan is harvested by paddy combine harvesters. Two-stage harvesting is currently the main harvesting method [Zhetpeisov, 2010]. Improper operating mode of the combine harvester leads to higher grain loss and lower output [Špokas and Steponavičius, 2010]. The main cause of the degraded performance and output of the combine harvester is incompatibility of feed rate with throughput capacity of the threshing unit and uneven distribution of the fed mass before threshing [Penkin et al, 1970, Taylor et al, 2005]. It is noteworthy that total energy consumption of a combine harvester as well as distribution of energy between the threshing unit and the undercarriage depends on the change of harvesting conditions [Zhong et al., 2013].

The available engineering solutions [Zhalnin and Savchenko, 1985] provide partial levelling of the rice mass when harvesting high-yield, higher humidity, twisted biomass, as the profiles of corrugations on the bottom plate of the feederhouse are positioned to form continuous branches that separate the flow to opposite directions. This disturbs the smooth and even levelling of the biomass flow down the trenches formed by V-shaped profiles of the corrugations, thus leading to partial, i.e. insufficient levelling of the flow of rice mass along the width of threshing unit [Sadykov et al., 2009].

In rice cultivation using harvesting technology largely similar, used in grain production. However, the methods proven harvesting grain crops often do not provide the necessary indicators for harvesting rice. This is explained by the special hydrological regime fields with prolonged flooding, and biological characteristics and physico-mechanical properties of rice [Portnov, 1988].

Analysis of rice harvesting process has suggested the hypothesis that the grain separation loss, grain damage, and energy consumption could be reduced by using optimised parameters of the work tools in the feederhouse of a combine harvester. In particular, the hypothesis assumes that quality grain at lower energy consumption is possible to achieve by using a levelling tool in the feederhouse that ensures uniform feed of the rice mass to the threshing zone by distributing the mass evenly along the length of the threshing cylinder. Thus ensuring thinner layer of the rice mass fed into the threshing unit.

As a result, scientific studies aimed at developing a work tool optimising the design and operating parameters of paddy harvesters are relevant today and are highly important from both the scientific and economic perspective.

Aim of the study. The study is aimed at studying the physical-mechanical properties of rice during harvesting and experimental testing of the process of levelling of the rice mass by the optimised work tool in the feederhouse, followed by subsequent identification of key factors that affect levelling of the layer of rice mass before threshing.

Object and methodology of the study

In case of two-stage harvesting, biomass is the thickest in the middle of the windrow and the thinnest along the edges in its original state (Fig. 1).The objective of the invention is sufficient, i.e. the maximum possible, levelling of the flow of high-yield, higher humidity and entangled rice mass along the width of feederhouse, i.e. the width of threshing unit 5. One of the possible solutions is fitting V-shaped corrugation profiles 3 at varying intervals on the bottom of the feederhouse 2 (Fig. 1). Intervals between the corrugations 3 are smaller at the entry part of the feederhouse than at the end. More complete levelling of the flow of biomass, in turn, leads to better separation of grain at the concave and lower torque at the threshing cylinder, positively affecting the output, quality, energy as well as other performance indicators of the combine harvester [Klenin, 1997].

The driven drum of feederhouse is positioned in the slots, resulting in the design clearance between the conveyor and the bottom plate at the entry. The operating direction of conveyor is set to ensure that the biomass flows between the conveyor and the bottom plate. The rice mass is fed into the feederhouse, caught by slats and dragged by the conveyor down the bottom plate.

The bottom plate is corrugated, and the corrugation profiles are positioned at varying intervals along the length of feederhouse. The rice mass flows to fill the empty spaces, i.e. moves from the centre of the bottom plate towards its edges. The corrugations provide even levelling of the mass along the width of feederhouse, and rice spikes are rubbed against the profile edges [Umbetaliev et al., 2010].

Degree of levelling of the rice mass layer, breakage of panicles and damage to rice grains has been set as the criteria of optimisation.

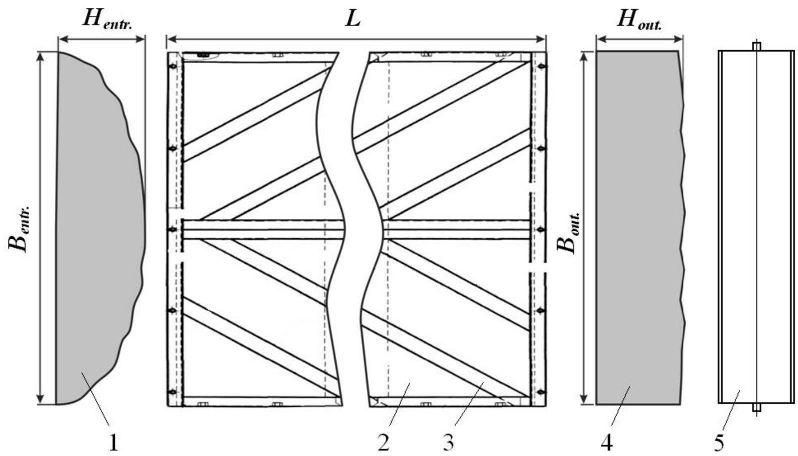

Fig. 1. Transformation of the rice mass layer along the width of threshing unit: $H_{entr.}$, $H_{out.}$ – windrow height at the entry and exit, $B_{entr.}$, $B_{out.}$ – windrow width at the entry (width of feederhouse) and exit, L – length of the bottom plate of the feederhouse, 1 – windrow, 2 – bottom plate of the feederhouse, 3 – corrugation, 4 – layer of rice mass, 5 – threshing cylinder

Levelling ratio of the rice mass layer was determined by the experimental assembly as follows Fig. 2. Coordinates of stem base and panicles of colours-coded stalks of a weighed batch were determined with reference to the centreline of feederhouse. The rice biomass was fed by the conveyor feeder 6 via adapter 3 into feederhouse 1 containing the corrugated levelling tools. Having passed the tested optimised work tools in the feederhouse, the rice biomass then entered the discharge conveyor 7. With the retaining unit 9 at the discharge conveyor adjusting the vertical position of mass and pushing it down the cut-out of frame. The displaced coordinates of the stem base of colours-coded stalks were measured by a metric ruler under the same reference system. Average numeric value of difference between the coordinates of the biggest and smallest displacement of the respective stalks was then calculated, and the levelling ratio of rice mass was estimated under the following equation:

$$\mu = \frac{\Sigma x_{\max} - \Sigma x_{\min}}{\Sigma x_{\max}}, \qquad (1)$$

$\Sigma x_{\max}$ – the biggest displacement of colour-coloured stalks, mm;
$\Sigma x_{\min}$ – the smallest displacement of colour-coded stalks, mm;
μ – levelling ratio.

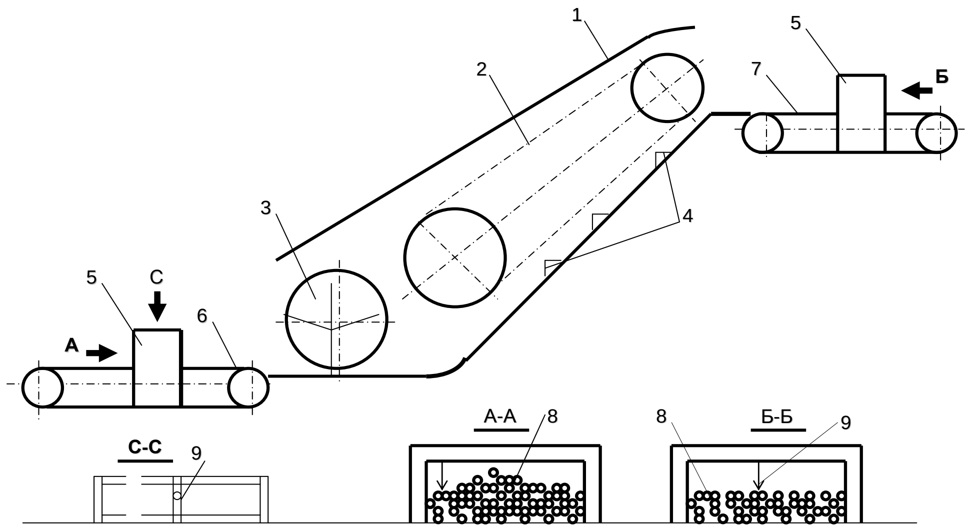

Fig. 2. Experimental laboratory assembly design for determination of levelling ratio (μ, %) of the rice mass layer: 1 – feederhouse (inclined chamber); 2 – conveyor; 3 – adapter; 4 – levelling tools (corrugations); 5 – unit UNK-1; 6 – feeder conveyor; 7 – discharge conveyor; 8 – rice mass; 9 – retaining unit

Performance indicators of the combine harvester at rice harvesting were determined during the second stage of study. The comparative experiments took place in Almaty region Karatalsky district at the agricultural production cooperative "Opitnoje". The experimental tests of the technological process of rice harvesting were conducted in accordance with GOST 12041-82 (national standard), GOST 12038-82 (national standard), OST 70.8.1.-81 (industry-specific standard), OCT 70.8.3-81 (industry-specific standard), and under the methodology developed by Kuban Scientific-Research Institute for Tractors and Agricultural Machinery (КубНИИТИМ).

Results and Discussion

The determined values of physical-mechanical properties of rice (variety "Ushtobinsky") during harvesting have suggested that the factors affecting the quality of technological threshing process vary within a wide range: density 265 ±25 stems/m^2, panicle length 15.5±2.7 cm, height of plant stand 78.0±7.0 cm, stalk diameter 3.3±0.2 mm.

Dependences of the levelling ratio of rice mass on the feed rate q have been determined (Fig. 3).

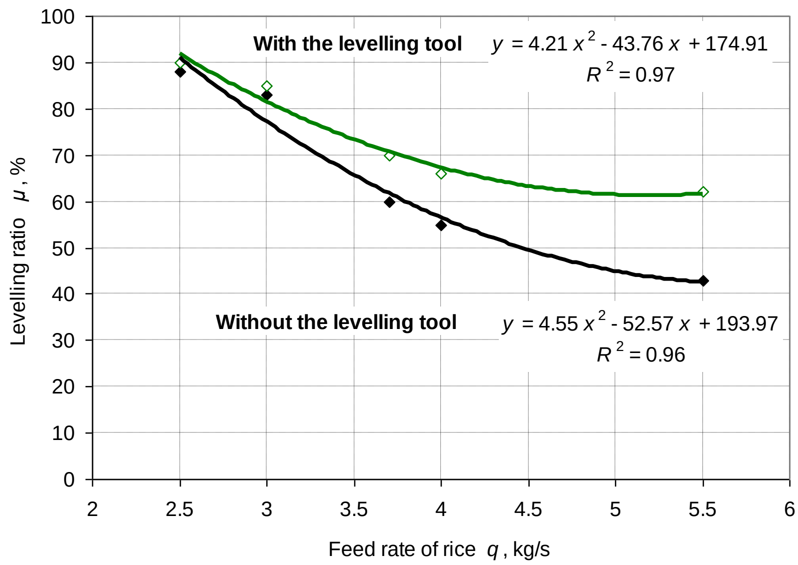

Fig. 3. Dependence of the feed rate q on levelling ratio of rice mass μ

Grain loss at the straw walker is known to be usually determined according to the thickness of the heap on the straw walker and then by the amount of straw mass fed [Zubkov, 1996, Steponavičius et al., 2011], which proves the assumption that the higher is the levelling ratio of rice mass, the less grain is lost in the straw separator.

Studies conducted by us have shown that the levelling ratio μ depends on the amount of feed of the rice mass layer into the feederhouse. The shown dependences prove the sensitivity of the levelling tool to overloads. For example, after the increase of feed rate from 3.4 kg/s of biomass to 5.5 kg/s (Fig. 3), the levelling ratio of rice mass without the levelling tool increases from 43% to 67%; with the levelling tool, respectively, from 62% to 75%.

Levelling ratio is also affected by physical-mechanical properties of rice, including humidity W of the biomass fed into the combine harvester (Fig. 4).

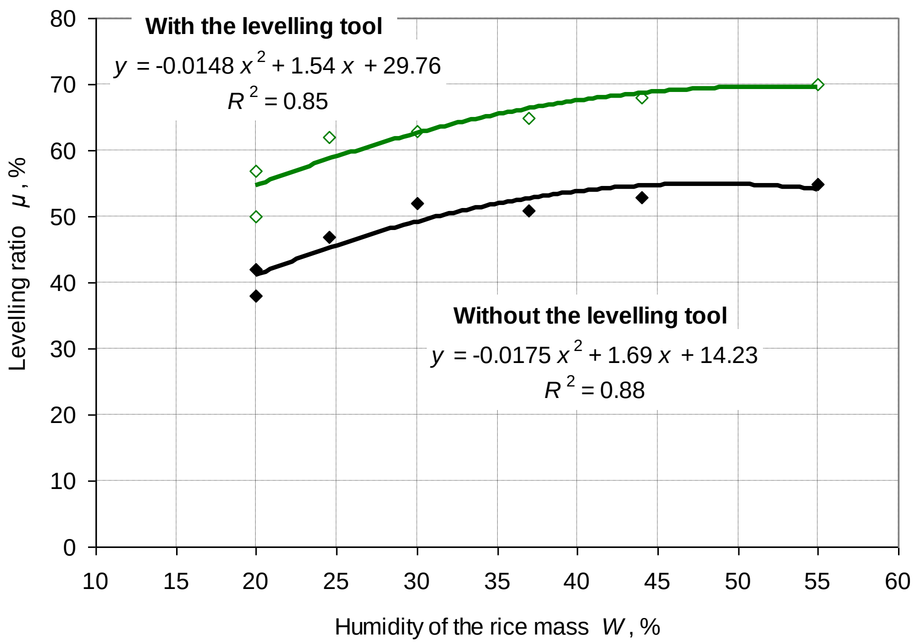

Fig. 4. Dependence the humidity of rice mass W on the levelling ratio μ

Figure 4 suggests that the increase of humidity of rice mass from 20% to 55%, i.e. by 2.8 times leads to increase of the levelling ratio μ from 53% to 70%, i.e. by 1.3 times, where the levelling tool has been used; and from 42% to 54%, i.e. by 1.2 times, without the levelling tool. The dependence of the levelling ratio of rice mass on the humidity has been found to be considerable lower than on the feed rate of mass into the combine harvester.

The influence of inconsistency in rice windrow on quality parameters of combine harvester performance has been studied by field experiments (Table 1). The more inconsistent the rice windrow, the higher is the amount of mechanically damaged grains. For example, in case of variation ratio of inconsistencies in a windrow μ=2.7%, the content of micro and macro damaged grains was, respectively, 3.6% and 1.9%; while in case of the variation ratio of μ=23.5% and 47.2%, the content of micro and macro damaged grains was, respectively, 4.2% and 4.7% or 2.9% and 2.8%, i.e. the content increased by 1.1–1.5 times. The amount of unthreshed panicles also increases: from 1.6% to 3.5%, i.e. almost 2-fold. This is due to differences in moisture content of the rice mass at individual sections of a windrow along its length, uneven feed rate into the threshing unit, which disturbs the running mode of work tools of the combine harvester.

Windrows with their variation ratio of length-wise inconsistency 3–8% provide more quality of combine harvester performance at the pick-up and threshing, and 1.5–2.0 times lower loss of grain, 20–30%

lower content of mechanically damaged grain, and 1.5–2.0 times less unthreshed panicles compared to threshing of a windrow with variation ratio of inconsistency 23.5–47.2%.

Table 1. Influence of inconsistency in a windrow on the quality of threshing

Fraction content in the grain tank of combine harvester	Windrow variation ratio of inconsistency, %			
	2.7	11.3	23.5	47.2
Whole grain, %	88.2	87.2	84.4	80.4
Unripe grain, %	1.8	1.6	1.7	1.6
Micro damaged grain, %	3.6	3.7	4.2	4.7
Macro damaged grain Crushed, %	1.9	2.0	2.4	2.9
Unthreshed panicle, %	1.6	2.3	2.4	3.5

The proposed rational structure of the optimised corrugated work tool for levelling high-yield rice mass in a feederhouse of combine harvester has been verified by field experiments (Table 2).

Table 2. Quality of threshing of rice windrows without and with the levelling tool (under the following optimum parameters: approach angle of corrugations α=55 degrees; height of corrugations h=37 mm; feed rate of rice biomass q=3.6 kg/s; intervals between corrugations i=70×95×120 mm)

Fraction content in the grain tank of combine harvester, %							
Without the levelling tool				With the levelling tool			
Whole grain	Micro damaged grain	Macro damaged grain	Unthre-shed panicle	Whole grain	Micro damaged grain	Macro damaged grain	Unthre-shed panicle
90.6	4.6	6.1	0.5	95.6	2.1	1.5	0.3
90.6	3.8	5.9	0.6	95.6	2.8	1.8	0.4
89.2	4.1	6.0	0.7	94.2	3.5	1.9	0.5
87.6	5.4	6.3	0.6	92.6	3.9	2.0	0.4
87.0	4.6	6.2	0.9	92.0	4.0	2.1	0.5
89.4	3.8	5.8	0.2	94.4	2.7	2.2	0.1
81.3	4.1	4.9	0.4	86.3	2.6	2.4	0.2
87.4	5.4	4.5	0.4	92.4	3.0	1.8	0.2
86.5	5.5	4.3	0.4	91.5	3.1	2.1	0.2
82.9	4.0	4.0	0.5	87.9	2.7	2.3	0.3
83.9	4.3	4.2	0.7	88.9	2.6	2.5	0.4
81.2	5.4	4.5	0.7	86.2	2.5	2.0	0.5
80.2	6.1	4.9	0.8	85.2	3.0	1.9	0.4
Average value with confidential level (±) at 95% probability							
85.98 ±2.22	**4.70 ±0.46**	**5.20 ±0.50**	**0.57 ±0.12**	**90.98 ±2.22**	**2.96 ±0.33**	**2.00 ±0.20**	**0.34 ±0.08**

The optimised levelling tool used during rice harvesting secures the technological process, ensures proper unloading of the threshing unit and transformation of the rice stalk mass into a uniform flow directed toward the threshing unit. The proposed technology of rice harvesting carries practical importance as it ensures levelling of high-yield layer of rice mass before threshing and is implemented by the levelling tool that considerably reduces the content of mechanically damaged rice grains (Table 2). Application of the designed levelling tool may lead to reduction in damaged grains by 2–2.5 percentage point, and about twice reduction in unthreshed panicle (threshing loss).

Conclusions

1. The determined values of physical-mechanical properties of rice (variety “Ushtobinsky”) during harvesting have suggested that the factors affecting the quality of technological threshing process vary within a wide range: density 265±25 stems/m^2, panicle length 15.5±2.7 cm, height of plant stand 78.0±7.0 cm, and stalk diameter 3.3±0.2 mm.
2. Laboratory assembly type UNK-1 of model ZKN 5–6B (certificate No. BA 03–082/06) has been designed for the experiments and new methodology for calculation of the levelling ration of rice mass before threshing has been developed.
3. To ensure more uniform levelling of high-yield rice mass in the feederhouse of a combine harvester, a rational design of an optimised work tool has been proposed; the influence of geometrical parameters of the work tool on the ratio of levelling of the rice mass layer before threshing has been determined.
4. The levelling ratio depends on the amount of the rice mass fed into the combine harvester. The levelling ratio is also influenced by physical-mechanical properties of rice, as well as its humidity. In case of increase of humidity from 20% to 55%, i.e. by 2.8 times, the levelling ratio has increased from 53% to 70%, or by 1.3 times, where the levelling tool has been used; and from 42% to 54%, or by 1.2 times, where the levelling tool is not used. The levelling ratio of rice mass is considerably less dependent on humidity than on the feed rate.

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