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Motnje v postopku hlajenja koruznega zrnja v vertikalnih gravitacijskih sušilnicah

Disturbances in the Process of Corn-Grain Cooling in Vertical Gravity Dryers

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Postopek sušenja koruznega zrnja običajno poteka tako, da zrnje vstopi v predel za ohlajevanje z vlažnostjo, ki je 2,0% nad ravnovesnim stanjem. Poleg tega, da se zrnje ohladi, se v predelu za ohlajevanje tudi osuši za 1,5% do 2,0%. Vendarle pa smo z našo raziskavo pokazali, da obstajajo tudi primeri, ko koruzno zrnje v predelu za ohlajevanje rehidrira za 0,65% do 4,26%.

Naša raziskava je vključevala tudi analizo vlažnosti koruznega zrnja vzdolž vodoravnega prereza hladilnika. V odvisnosti od mesta zbiranja vzorcev je razlika v vlažnosti koruznih zrn nihala od 1,99% do 4,35% ter v nekaterih skrajnih primerih dosegla celo 10,0%.

Ti pojavi so povzročili večjo porabo energije, zmanjšanje zmogljivosti sušilnice in neenakomerno osušenost koruznega zrnja.

(Ključne besede: rehidracija, cone hladilne, sušenje, zrnje koruzno)

The process of corn-grain drying is usually conducted in such a way that corn grains come into a cooler zone at a moisture level that is 2.0% higher than the equilibrium level. As well as being cooled, the corn grains in the cooler zone also get dried by between 1.5% and 2.0%. However, our research has shown that this is not always the case, since corn grains are sometimes re-hydrated in the cooler zone by 0.65% to 4.26%.

Our research also included an analysis of the moisture levels of corn grains in the horizontal section of the cooler zone. Depending on the location, the difference in the moisture levels of the corn grains varied from 1.99% to 4.35%, reaching as much as 10.0% in some extreme cases.

This resulted in a higher energy consumption, a decrease in capacity and heterogeneously dried corn grains.

(Keywords: re-hydration, cooling zones, drying, corn grains)

0 UVOD

Kmetijske zrnate pridelke običajno sušimo v navpičnih gravitacijskih sušilnicah. Te sušilnice so sestavljene iz dveh delov: dve tretjini sta namenjeni sušenju, ena tretjina pa hlajenju. Med postopkom sušenja se vlažnost zrnja zmanjša do določene ravni, ki je odvisna od vrste sušenega zrnja (oljnice ali žitarice), od njegove uporabe in od načrtovane dobe njegovega skladiščenja. Po končanem postopku sušenja segreto zrnje ohladimo v predelu za ohlajevanje, tako da je temperatura zrnja, ki zapušča sušilnik, 5°C nižja od temperature zunanje okolice. Poleg tega, da se ohladi, se zrnje tudi

0 INTRODUCTION

Agricultural grain products are usually dried in vertical gravity dryers. These vertical gravity dryers consist of two zones: two-thirds of the dryer is the drying zone and one-third is the cooling zone. During the process of drying, the moisture level in the grain is decreased to a certain level, depending on the type of grain being dried (oilseed or cereal), on how it will be used in the future and on the planned period of storage for the grain. After the drying process the warm grain is cooled in the cooling zone in order to keep the temperature of the grain as it exits the dryer 5ºC less than the temperature of the external environment. In addidodatno osuši za 1,5 do 2,0%, ker v predelu za ohlajevanje vroče zrnje pride v stik z vlažnim zrakom in med njima nastane termodinamični stik. Vlažni zrak namreč odvede toploto segretega zrnja in se tako segreje. Hkrati obe sredstvi tudi izmenjata vlago, pri čemer poteka prenos vlage v obeh smereh. Smer prenosa vlage je odvisna od delnega tlaka vlage na površini zrnja in od tlaka vlažnega zraka, kajti tako zrnje kakor tudi vlažen zrak se nagibata k termodinamičnemu ravnovesju.

Na Hrvaškem se že več let srečujemo s problemom ohlajanja zrnja, ki je del postopka sušenja v navpičnih gravitacijskih sušilnicah. V zgodnjih sedemdesetih letih smo opazovali pomembne učinke hitrosti hlajenja zrnja, ki sledi postopku njegovega sušenja, ter ugotovili tesno povezavo med povečano poškodovanostjo zrnja in povečano hitrostjo hlajenja [1]. Prav tako smo opazili, da v primeru sušenja pri različnih hitrostih ni prišlo do odvisnosti med povečano poškodovanostjo zrnja in povečano hitrostjo sušenja, če smo zrnje ohlajali počasi. Ugotovili smo tudi, da različni hibridi kažejo različne hitrosti sproščanja vode iz zrnja, kar je posledica razlik v sestavi semenskih mešičkov. Sestava semenskih mešičkov kaže največjo odpornost do sproščanja vode, oziroma do oddajanja vodne pare v času sušenja ([2] in [3]). Na temelju predhodnih del številnih avtorjev sta Martins in Stroshine [4] raziskala vpliv vlažnosti koruznega zrnja na hitrost sušenja zrnja. V raziskavi sta za vsak hibrid uporabila tri različne ravni vlažnosti zrnja; za raziskavo sta porabila tri leta. Avtorja sta ugotovila, da so se hibridi obnašali različno v različnih vremenskih razmerah v posameznih letih raziskovanja. Ta ugotovitev je številne druge avtorje vzpodbudila, da so začeli raziskovati in ugotavljati problem “motenj” v hladilniku sušilnice. V raziskavi, ki so jo izvedli Katić in Krička [5] ter Krička in Pliestić [6], so avtorji ugotovili, da koruzno zrnje ob vstopu v hladilnik ni bilo dovolj osušeno in da je bila razlika med vlažnostjo zrnja ob vstopu in izstopu iz hladilnika -3.81%.

Namen številnih nadaljnjih študij je bila tudi določitev razlike v vlažnosti zrn ob izstopu iz hladilnika, saj so raziskave pokazale, da je bila povprečna vlažnost zrnja v silosih 15,50%, medtem ko je v zapisniku osuševalnega postopka povprečna vlažnost znašala 13,50%. Z zapisovanjem podatkov o homogenosti mase v sušilnici so avtorji ugotovili, da so vzorci vsebovali zrnje z 11,0% vlažnostjo, da

tion to being cooled down, the grain is also dried by an additional 1.5% to 2.0%, because in the cooling zone the hot grain comes into contact with the humid air, and there is thermodynamic contact between the two media. The surrounding humid air conducts the heat away from the hot grain and, as a consequence, becomes hotter in the process. At the same time, the two media exchange moisture, with the moisture transfer occurring in both directions. The direction of the transfer of the moisture depends on the partial pressure of the moisture on the grain surface and the pressure of the humid air, because both the grain and the humid air tend to reach a state of thermodynamic equilibrium.

For a number of years Croatia has encountered problems with grain cooling during the drying process in vertical gravity dryers. Significant effects of the cooling speed after the drying of the grain were observed in the early 1970s, and a close correlation was found between increased grain damage and increased cooling speed [1]. It was also observed that when drying at various speeds, there was no correlation between increased grain damage and increased drying speed if a slow cooling speed was used. It was also found that different hybrids exhibit a variety of water-release rates from the grain, resulting from differences in the grain’s pericarp structure. This pericarp structure shows the greatest resistance to the passage of water, i.e., the transfer of water vapour during the drying process ([2] and [3]). Based on the work of a number of authors, Martins and Stroshine (1987) [4] researched the influence of corn-grain moisture on the drying speed of the grain. The research was conducted using three different grain-moisture levels for each hybrid, and took a total of three years. The authors found that the hybrids exhibited different behaviours, depending on the weather conditions for the particular year. This led a number of authors to begin researching and defining the problem of the “disturbance” in the cooler of the dryer. In the research conducted by Katić and Krička (1988) [5] and Krička and Pliestić [6], it was determined that the corn grain was not dry enough when it entered the cooler, and that the difference in the grain’s moisture level between its entering and exiting the cooler was -3.81%.

The aim of numerous studies was also to determine the difference in the moisture levels of the grain as it exited the cooler, because it was found that the average grain moisture level in silo units was 15.50%, whereas it was 13.50% in the drying record books. By keeping records of the homogeny of the mass in the dryer, it was found that samples pa je bilo v masi tudi zrnje, katerega vlažnost se je povzpela na 16,0% ali celo 17%. Z obdelavo podatkov vzorčnih meritev so tudi dokazali, da se je razlika v vlažnosti zrn gibala med -1,25% in -4,35% ([7] do [9]).

Neizenačenost v vlažnosti koruznih zrn ob izstopu iz sušilnice vpliva na mikrobiološke in toksikološke značilnosti zrnja pa tudi na neoporečnost zrnja, ki je potrebna za nadaljnjo predelavo. Nekateri avtorji ([3], [10] do [12]) trdijo, da ima preveč osušeno zrnje (pod 6% vlažnostjo) večji delež proteina zaradi koncentracije suhe snovi, a da to hkrati vodi tudi do zmanjšane prebavljivosti proteina, oziroma do njegovega denaturiranja in zmanjšane topljivosti. Ti avtorji so tudi opozorili, da s povprečno 14% vlažnostjo ni mogoče zagotavljati neoporečnih mikrobioloških in toksikoloških značilnosti mase koruznega zrnja, saj takšna masa vsebuje zrnje z zelo majhno vlažnostjo (do 4,7%) in tudi zrnje z veliko vlažnostjo (do 20,4%).

Z zapisovanjem podatkov o kakovosti koruznega zrnja, skladiščenega po končanem postopku sušenja, ter uporabo zaznaval in mikrobiološke analize smo ugotovili, da zrnje ne ustreza zahtevanim mikrobiološkim kriterijem. To pomeni, da zrnje ni primerno za skladiščenje, saj se je v času skladiščenja kvarilo, na njem pa se je pojavljala plesen; dodati je sicer treba, da se to ni dogajalo z vsemi zrni. Ugotovili smo tudi, da se število pokvarjenih zrn povečuje z daljšanjem dobe skladiščenja. Medtem ko smo ugotavljali, zakaj zrnje ni primerno za skladiščenje, čeprav ima ob izhodu iz sušilnice zadovoljivo vlažnost, smo v hladilnem delu sušilnika opazili določene motnje. Nadaljnja raziskava je pokazala na očitno razliko med povprečno vlažnostjo vzorčnega koruznega zrnja, vzetega z vrha sušilnice, ter zrnja, vzetega iz transporterja. Še večje razlike pa smo ugotovili med posamičnimi zrni, zajetimi vzdolž prereza sušilnice.

Cilj našega dela je bil raziskati in pojasniti pojav, ki se dogaja v hladilniku.

1 MATERIALI IN METODE

Raziskava je potekala ob sušilnih napravah v Republiki Hrvaški, v skladu s "Predpisi za izgradnjo in ocenjevanje sušilnih naprav za kmetijske pridelke" in je trajala pet let. Zahtevane parametre raziskave smo določili z definiranjem vhodne in izhodne energije ter količine vode. Za določitev motenj v hladilniku sušilnice smo

contain grains with 11.0% moisture, but there were also grains with a moisture content as high as 16.0 to 17.0%. Processing the sample-measurement data proved that the differences in the moisture in the grain range from -1.25% to -4.35% ([7] to [9]).

The differences in corn-grain moisture at the exit of the dryer influence the microbiological and toxicological properties of the grain as well as its acceptability for food processing. Some authors ([3], [10] to [12]) claim that an over-dried grain (under 6% moisture) has a larger protein content due to dry-matter concentration, but that this also leads to lower protein digestibility, i.e., its denaturation, and lower solubility. These same authors determined that it is impossible to maintain acceptable microbiological and toxicological properties of the corn-grain mass with an average moisture level of 14%, because such a mass contains grains with moisture levels as low as 4.7% and as high as 20.4%.

By keeping a record of the quality of stored corn grain after drying, using sensory and microbiological analysis, it was found that the grain does not satisfy the required microbiological criteria. This means that the grain is not suitable for storing, and while the grain was being stored it tended to spoil and fungus appeared; however, this was not the case for all grains. The number of spoiled grains was also found to increase with longer storage times. While looking for the reason why the corn grain is not suitable for storage, despite a satisfactory corn-grain moisture level at the exit of the dryer, certain disturbances in the cooling zone of the dryer were found. The investigation revealed a noticeable difference between the average moisture levels of the corn-grain samples taken from the top of the dryer and those taken from the exit transporter. Even larger differences were noticed in certain samples taken along the cut of the dryer.

The aim of our research was to explore and to explain this phenomenon that is taking place in the cooler.

1 MATERIALS AND METHODS

The research was conducted at drying facilities in the Republic of Croatia in accordance with the "Regulations for the construction and evaluation of drying facilities for agricultural products" over a period of five years. The required parameters for the research were set by fixing the quantities of input and output energy and the amount of water. In order to determine the disanalizirali parametre, ki so opisani v naslednjem odstavku.

Da bi prišli do sklepov raziskave vzdolž vodoravnega prereza, smo analizirali temperaturo in vlažnost zrn, ki vstopajo v sušilnico (A). Nato smo ista parametra ocenili vzdolž poševnega prereza pokrova sušilnice na treh točkah – na začetku, v sredini in na koncu – odvisno od lege vetril v sušilnici (B). Ista parametra, temperaturo in vlažnost zrn, smo preverili tudi ob izhodu iz sušilnice (C). Da bi lahko sledili spremembam vzdolž vodoravnega prereza, smo merili tudi temperaturo in relativno vlažnost zunanjega zraka. Da pa smo lahko sledili spremembam vzdolž navpičnega prereza hladilnika v sušilnici, smo določili maso ob vhodu in izhodu iz sušilnice, prav tako pa tudi vlažnost in temperaturo zrn ob vhodu in izhodu iz sušilnice. Določili smo tudi vlažnost in temperaturo zrn ob vhodu in izhodu iz hladilnega dela, pa tudi temperaturo in relativno vlažnost zunanjega zraka. Vzorčno zrnje smo vzdolž prereza sušilnice jemali s posebnimi kleščami.

Vlažnost koruznih zrn smo določili z običajno vzorčno metodo, tj. s sušenjem vzorcev zrn v laboratorijski sušilnici in z uporabo hitrega merilnika vlage (Dickey John GAC 2000). Razmere v okolju – temperaturo in relativno vlažnost zunanjega zraka – smo merili z psihrometrom; hitrost zraka v sušilnici pa smo določili z digitalnim anemometrom. Temperaturo zraka in zrnja v sušilnici smo merili z merilno glavo PT (PT 100 in PT 1000), temperaturo koruznega zrnja zunaj vročega zračnega toka pa smo merili z digitalnim termometrom s toleranco ±0,1°C.

Da bi določili razliko v masi zrnja ob vhodu in izhodu sušilnice, smo uporabili tehnično skalo z natančnostjo razreda A. Vzdolž vodoravnega prereza sušilnice smo vzorce zajemali s posebnimi kleščami. Te vzorce smo vzeli na začetku, v sredini in na koncu pokrova sušilnice. Da bi ugotovili stopnjo enakomernosti osušenih zrn, smo morali zajeti vzorčno zrnje na različnih mestih v hladilniku sušilnice. Vzorce koruznih zrn smo zajeli ob vhodu v sušilnico in tik pod krivino izpustne enote. Da bi preverili delovanje hladilnika vzdolž navpičnega prereza sušilnice in ugotovili mogočo "nepravilnost hladilnika", smo vzorce zrn zajeli ob vhodu in izhodu iz sušilnice. Upoštevali smo tudi vzorec celotne mase. Izgube zaradi nepravilnosti v

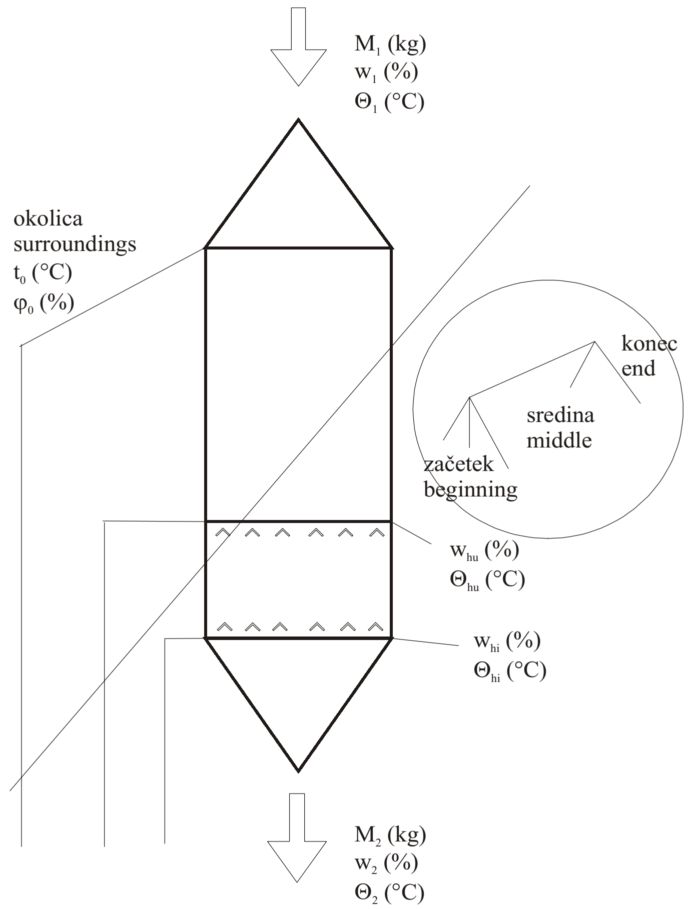
turbances in the cooler of a dryer, the following parameters, described in the next paragraph, were analyzed.

In order to draw conclusions about the horizontal cut, the temperature and the moisture levels of the grains entering the dryer (A) were analyzed. Next, the same parameters were assessed at the diagonal cut of the top at three places – at the beginning, the middle and the end of the top – depending on the locations of the ventilators in the dryer (B). The same parameters, the moisture levels and the temperature of the grains, were taken at the exit of the dryer (C). In order to track changes along the horizontal cut we also measured the temperature and the relative humidity of the surrounding air. In order to track changes along the vertical cut of the cooler in the dryer we fixed the mass at the entrance and at the exit of the dryer, as well as the humidity and the temperature of the grains at the entrance and the exit of the dryer. We also fixed the moisture levels and the temperature of the grains at the entrance and the exit of the cooling zone, as well as the temperature and the relative humidity of the surrounding air. The grain samples from the cut of the dryer were taken using special pliers.

The corn-grain moisture level was determined using the standard etalon method, i.e., by drying the grain samples in a laboratory dryer and using a quick moisture-measuring meter (Dickey John GAC 2000). The environmental conditions – the temperature and the relative humidity of the air surrounding the dryers – were measured with a psychrometer, and the speed of the air in the dryer was determined with a digital anemometer. The temperatures of the air and the grain in the dryer were measured with PT probes (PT 100 and PT 1000), whereas the temperature of the corn grains outside the hot air stream was measured using a digital thermometer with an uncertainty of ±0.1ºC.

In order to determine the difference in the grain mass at the dryer's entrance and exit we used a technical scale with class "A" precision. Samples were taken from along the horizontal cut of the dryer using special pliers. These samples were taken at the beginning, the middle and the end of the dryer top. In order to determine the uniformity of the dried grains, it was necessary to take samples at various places in the dryer's cooler. The corn-grain samples were taken at the entrance to the dryer and immediately under the concave discharge. In order to examine the operating of the cooler along the vertical cut of the dryer, and to locate possible "cooler disorder", the grain samples were taken at the entrance and at the exit of the dryer. An overall sample was also taken. The losses due to irregularities in the process were expressed postopku smo izrazili z razliko med maso ob vstopu v sušilnico in maso ob izhodu iz sušilnice. Slika 1 kaže parametre, ki smo jih upoštevali in mesta, na katerih smo te parametre merili.

using the difference between the dryer-entry mass and the dryer-exit mass. Figure 1 shows which parameters were taken into account and the locations where they were measured.



Legenda:

M_1 (kg/h) masa koruznega zrnja ob vhodu v sušilnico
M_2 (kg/h) masa koruznega zrnja ob izhodu iz sušilnice
w_1 (%) vlažnost koruznega zrnja ob vhodu v sušilnico
θ_1 (°C) temperatura koruznega zrnja ob vhodu v sušilnico
W_{HU} (%) masa koruznega zrnja ob izhodu iz sušilnice
θ_{HU} (°C) temperatura koruznega zrnja ob vhodu v sušilnico
w_{HI} (%) vlažnost koruznega zrnja ob izhodu iz hladilnega dela sušilnice
θ_{HI} (°C) temperatura koruznega zrnja ob izhodu iz hladilnega dela sušilnice
w_2 (%) vlažnost koruznega zrnja ob izhodu iz sušilnice
θ_2 (°C) temperatura koruznega zrmja ob izhodu iz sušilnice
t_0 (°C) temperatura zunanjega zraka
φ_0 (%) relativna vlažnost zraka

Key:

M_1 (kg/h) corn-grain mass at the entrance to the dryer
M_2 (kg/h) corn-grain mass at the exit of the dryer
w_1 (%) corn-grain moisture at the entrance to the dryer
θ_1 (°C) corn-grain temperature at the entrance of the dryer
W_{HU} (%) corn-grain mass at the exit of the dryer
θ_{HU} (°C) corn-grain temperature at the entrance to the dryer
w_{HI} (%) corn-grain moisture at the exit of the dryer's cooler
θ_{HI} (°C) corn-grain temperature at the exit of the dryer's cooler
w_2 (%) corn-grain moisture at the exit of the dryer
θ_2 (°C) corn-grain temperature at the exit of the dryer
t_0 (°C) surrounding air temperature
φ_0 (%) relative air humidity

Sl. 1. *Prikaz merjenih parametrov*
Fig. 1. *Diagram of measured parameters*

2 REZULTATI RAZISKAVE IN RAZPRAVA

2.1 Razprava o rezultatih, pridobljenih vzdolž vodoravnega prereza hladilnika

Preglednica 1 prikazuje meritve, izvedene vzdolž vodoravnega prereza sušilnice; preglednica 2 prikazuje meritve, izvedene na različnih mestih v obdobju petih let in so utemeljene na meritvah iz

2 RESEARCH RESULTS AND DISCUSSION

2.1 Discussion based on the results from the horizontal cut of the cooler

Table 1 shows the measurements taken from along the horizontal cut of the dryer; Table 2 shows the measurements from various locations during the period of five years, based on the measurements

Preglednica 1. *Prikaz meritev vlažnosti glede na čas in mesto analize zrnja vzdolž vodoravnega prereza sušilnice*

Table 1. *Chart of moisture-content measurements with respect to the time and the location of the sample along the horizontal cut of the dryer*

Zaporedna št. meritev / No. of measurement		**Izbrani pokrovi sušilnice / Tops** 6	5	4	3	2	1	**w (%)**	**w_r (%)**
1.	zač/beg	9,3	12,7	7,9	8,8	9,6	9,1	9,8	12,8
	sre/mid	13,5	10,6	7,4	7,0	8,9	14,0		
	kon/end	11,6	7,3	5,2	14,2	10,0	9,9		
2.	zač/beg	11,2	9,6	11,7	9,8	9,6	11,5	10,3	12,1
	sre/mid	11,8	13,0	8,4	9,2	11,7	14,0		
	kon/end	10,3	8,2	5,4	6,9	12,9	11,0		
3.	zač/beg	9,0	12,6	7,4	8,1	9,6	10,1	9,7	11,6
	sre/mid	8,7	9,2	7,4	8,5	9,2	10,9		
	kon/end	8,8	7,6	4,9	5,7	11,1	8,5		
4.	zač/beg	8,2	11,6	8,3	7,3	9,1	10,6	9,2	11,6
	sre/mid	10,8	7,5	9,5	8,3	10,0	9,5		
	kon/end	10,1	9,2	4,7	7,3	12,3	11,7		
5.	zač/beg	9,2	12,9	10,3	9,0	9,9	10,2	9,8	12,4
	sre/mid	14,1	11,1	8,6	8,7	13,2	10,3		
	kon/end	9,6	7,6	5,6	7,9	9,8	8,6		
6.	zač/beg	9,4	14,0	10,3	7,5	8,9	9,3	9,4	12,4
	sre/mid	10,9	12,2	9,1	9,0	11,0	13,1		
	kon/end	8,9	7,3	5,1	6,6	9,9	8,5		
7.	zač/beg	8,5	10,7	8,0	9,5	9,1	9,9	8,7	12,3
	sre/mid	8,5	9,7	8,5	7,9	10,0	10,3		
	kon/end	7,6	7,3	4,5	6,0	10,3	9,9		
8.	zač/beg	8,9	11,2	9,1	8,8	10,2	10,4	10,4	13,4
	sre/mid	11,6	13,5	10,4	8,5	10,3	12,8		
	kon/end	8,9	9,2	6,0	8,9	14,1	14,5		
Povp. na pokrovu Average per top	zač/beg	9,21	11,91	9,13	8,60	9,50	10,14		
	sre/mid	11,24	10,85	8,66	8,39	10,53	11,86		
	kon/end	9,46	7,96	5,18	7,98	11,30	10,33		
NKO LSD	zač/beg	n.s.	n.s.	n.s.	n.s.	n.s.	*		
	sre/mid	n.s.	n.s.	n.s.	**	**	*		
	kon/end	n.s.	**	n.s.	**	**	n.s.		
Seštevek vseh meritev Total of all measurements		**(n = 144) 9,55 (n = 8) x = 12,36**							

Legenda:

w (%) povprečna vsebnost vlage vzdolž prereza

w_r (%) vlažnost na transporterju

NKO najmanjše kvadratno odstopanje, odstopanje rezultatov meritev na vzorcih iz različnih točk vzdolž vsakega pokrova

* označuje pomembnost pri 5% verjetnosti, kakor to določa test F

** označuje pomembnost pri 1% verjetnosti, kakor to določa test F

Key:

w (%) average moisture content along the cut

w_r (%) moisture on the exit transporter

LSD least-square deviation, deviation of the results obtained for different points along each top

* denotes significance at the 5% level of probability, as determined by the F test

** denotes significance at the 1% level of probability, as determent by the F test

Preglednica 2. *Povprečne vrednosti vlažnosti koruznega zrnja in njegove temperature, pridobljene v petih letih*
Table 2. *Average values of the corn-grain moisture content and the corn-grain temperature sampling conducted over the five-year period*

Leto raziskave Year of research	**Vzorec Sample**	**Povprečna vrednost Average value**		**Razpon vsebnosti vlage Range of moisture content w**			**t_o (^oC)**	**φ_o (%)**
		w (%)	**θ (^oC)**	**min (%)**	**max (%)**	**Δw (%)**		
1	A	29,80	9,32	25,70	32,70			
	B	9,55	12,70	4,50	14,50	10,0		
	C	12,36	11,30	11,60	13,40		4,6	81,30
2	A	34,45	14,50	33,10	36,70			
	B	12,27	13,10	9,40	15,00	5,6		
	C	14,34	12,20	13,86	14,55		3,2	80,60
3	A	33,48	5,03	28,79	35,71			
	B	11,20	21,18	8,20	16,20	8,0		
	C	12,74	15,48	11,50	14,00		-0,2	92,50
4	A	35,10	19,6	32,80	36,59			
	B	9,13	25,5	8,20	14,02	5,82		
	C	13,47	25,2	12,00	14,75		19,3	83,70
5	A	33,31	19,46	31,40	34,92			
	B	7,90	26,91	5,50	9,58	4,08		
	C	13,75	26,10	12,80	14,95		19,7	82,90

Legenda:
A zrnje ob vstopu v sušilnico*
B zrnje ob vodoravnem preseku sušilnice**
C zrnje tik pred krivino izpustne enote*
* povprečna vrednost predstavlja 8 posamičnih meritev za w in 8 meritev za q
** povprečna vrednost predstavlja 144 posamičnih meritev za w in 144 meritev za θ

Key:
A grain entering the dryer *
B grain at the horizontal cut of the dryer **
C grain immediately before the concave discharge*
* one average represents 8 separate measurements for w and 8 for q
** one average represents 144 separate measurements for w and 144 for θ

preglednice 1. Preglednica 2 navaja povprečno vlažnost zrnja in temperaturo ob vhodu v sušilnico, pa tudi njune vrednosti, dobljene vzdolž vodoravnega prereza sušilnice in tik pred krivino izpustne enote. Preglednica 2 prikazuje tudi razpon od najmanjše do največje vlažnosti zrnja.

Rezultati meritev kažejo, da je v povprečju pod pokrovi 3, 4 in 5 največja vsebnost vlage zrnja ugotovljena ob začetku pokrovov, pod pokrovoma 1 in 6 pa je bila največja vsebnost vlage ugotovljena na sredini. Mesto ob koncu pokrova 2 je imelo največjo vsebnost vlage. Če opazujemo razlike med povprečnimi vrednostmi vlage pod posameznimi pokrovi, tj. med vzorčnimi zrni, zajetimi na začetku, sredini in koncu pokrova, lahko povzamemo, da so največje razlike v vsebnosti vlage v vzorcih, zajetih na začetku in koncu ugotovljene pod pokrovi 2, 3, 4 in 5, medtem ko je pri pokrovih 1 in 6 največja razlika v vsebnosti vlage ugotovljena med vzorci, zajetimi

shown in Table 1. The table shows the average grain humidity and the temperature at the entrance to the dryer, as well as those along the horizontal cut of the dryer and immediately before the concave discharge. The table also shows the range of the minimum and maximum grain-moisture content.

The results indicate that, on average, for tops 3, 4 and 5 the highest moisture content was found at the beginning of the tops, whereas with tops 1 and 6 the highest moisture content was, on average, detected in the middle. The end of top 2 had the highest moisture content. If we observe the differences between the average moisture values inside a single top, i.e., between the grain samples taken from the beginning, the middle and the end of a top, we can conclude that the largest differences in grain-moisture content between the samples taken at the beginning and the end of a top are found for tops 2, 3, 4 and 5, whereas tops 1 and 6 exhibit the na začetku in na sredini. Največja povprečna razlika v vsebnosti vlage, tj. 3,99%, je bila ugotovljena pod pokrovom 5, najmanjša povprečna razlika, tj. 0,62%, pa pod pokrovom 3.

Obdelava statističnih podatkov (enosmerna analiza) je pokazala na statistično pomembno razliko v vsebnosti vlage v vzorčnih zrnih, vzetih na začetku, sredini in koncu posameznega pokrova. V primeru vzorcev izpod pokrovov 1 in 3 nismo ugotovili statistično pomembnih razlik v vsebnosti vlage; pač pa smo našli pomembne razlike pri zrnih, zajetih izpod pokrovov 2, 4, 5, in 6. Statistično pomembno razliko v vsebnosti vlage smo ugotovili med vzorci, vzetimi na začetku in koncu pokrova 2, in sicer z 1-odstotno toleranco. Pri pokrovu 4 smo opazili statistično pomembno razliko v vsebnosti vlage med vzorci, vzetimi s sredine in s konca, in sicer z 1-odstotno toleranco. Enake rezultate z enako toleranco smo ugotovili tudi pod pokrovom 5, pod pokrovom 6 pa smo s 5-odstotno toleranco ugotovili pomembno razliko med vzorci, vzetimi na začetku in koncu, pa tudi med vzorci, vzetimi s sredine in konca.

Preglednica 2 vsebuje povprečja vsebnosti vlage in temperature koruznega zrnja vzdolž vodoravnega prereza hladilnika sušilnice in okoliškega zraka na vseh mestih zajema vzorcev v obdobju petih let. Očitno je, da se je največja razlika v vsebnosti vlage v zrnju (10,0%) vzdolž vodoravnega prereza sušilnice pojavila v prvem letu, čeravno smo tega leta izmerili tudi najnižjo povprečno vsebnost vlage (29,80%). Najmanjšo razliko v vsebnosti vlage v zrnju (4,08%) vzdolž vodoravnega prereza sušilnice smo opazili v zadnjem letu naše raziskave.

Očitno je tudi, da v nobenem letu zrnje ni bilo zadovoljivo ohlajeno, kar pomeni, da je temperatura zrnja ob izhodu iz hladilnika presegala dovoljeno razliko 5°C, tj. največjo dovoljeno temperaturno razliko med zrnjem in zunanjim zrakom. Ta razlika je bila največja v tretjem letu raziskave (15,68%).

To leto je bilo tudi najbolj mrzlo, kar povejo podatki temperature zunanjega zraka; za to leto je bila značilna tudi največja povprečna relativna vlažnost zraka (92,50%). Preglednica 2 prikazuje tudi razliko v povprečni vsebnosti vlage v zrnju tik pred krivino izpustne enote. Največjo povprečno vlažnost smo opazili v drugem letu raziskave pri vzorcih, zajetih tik pred krivino izpustne enote (14,34%), najnižjo vlažnost pa smo opazili v prvem letu raziskave pri vzorcih, zajetih tik pred krivino izpustne enote (12,36%).

largest moisture-content difference between the grain samples taken at the beginning and the middle of the top. The biggest average difference in grain moisture, i.e. 3.99%, was found for top 5, and the smallest average difference was found for top 3, i.e. 0.62%.

The statistical data processing (uni-directional variant analysis) showed a statistically significant difference in the moisture content of the corn-grain samples taken from the beginning, the middle and the end of a single top. No statistically significant difference in the moisture content was observed for the place where the samples were taken for the samples from tops 1 and 3. However, a significant difference was found for tops 2, 4, 5 and 6. A statistically justified difference in the grain moisture content between the samples taken at the beginning and the end was found at top 2, with an uncertainty of 1%. Top 4 showed a statistically significant difference in grain moisture content between the samples taken from the middle and the end of the top, with an uncertainty of 1%. The same results with the same error were found for top 5, whereas top 6 showed a significant difference between samples taken at the beginning and the end, as well as between the samples taken from the middle and the end, with an uncertainty of 5%.

Table 2 contains the corn-grain moisture content and temperature averages along the horizontal cut of the dryer's cooler and the surrounding air at all locations during the period of five years. It is clear that the biggest difference in the grain moisture content (10.0%) along the horizontal cut of the dryer appears in the first year, although we measured the lowest average grain moisture content (29.80%). The least difference in grain moisture content (4.08%) along the horizontal cut of the dryer was observed during the last year of the study.

It is also clear that in none of the years were the grains cooled sufficiently, which means that the grain temperature at the exit of the cooler was higher than the allowed 5°C difference, i.e., the maximum temperature difference allowed between the grain and the surrounding air. This difference was the largest in the third year of the study (15.68%).

This year was also the coldest, as can be seen from the air-temperature data; it also had the highest average relative air humidity (92.50%). In addition, table 2 shows the difference in average grain moisture content immediately before the concave discharge. The highest average humidity was observed during the second year of the study in the samples taken immediately before the concave discharge (14.34%), whereas the lowest humidity was observed in the first year of the study in the samples taken immediately before the concave discharge (12.36%).

Po postopku ohlajanja v hladilniku je toplo zrnje ohlajeno in dodatno osušeno za 1,5% do 2,0%. A v primerih, ko sta postopka izmenjave energije in snovi motena in ko se zrnje v hladilniku navlaži, govorimo o »motnji v hladilniku«.

Vemo, da se v nekaterih sušilnicah zrnje vzdolž vodoravnega prereza stolpa osuši neenakomerno, tako da se vlažnost nekaterih zrn ob izhodu iz sušilnice razlikuje od vlažnosti celotne mase, kar pa ni posledica neenakomernega sušenja nekaterih hibridov zaradi njihove morfologije ali neenakomernega sušenja, povezanega z različnimi vstopnimi vsebnostmi vlage v zrnju, na kar so opozorili Martins in Stroshine, [4] ter Bratko, [10]. Ta pojav (neobičajno obnašanje koruznega zrnja v času skladiščenja) lahko razložimo z absorpcijsko izotermo, ki je značilna za žitarice. Zrnje, ki se je po končanem postopku osuševanja spet navlažilo, spremeni svojo absorpcijsko izotermo. Ta sprememba nastane zaradi nepovratnih sprememb v strukturi zrnja in vodi v histerezo, ki ustvarja 1,5 do 2,0-odstotno razliko v vlažnosti zrn.

Vse te spremembe so pravzaprav posledica slabe gradnje stolpa sušilnice in transportnih elementov. Kolikor vemo, doslej podobnih raziskav še ni bilo in zato ne moremo primerjati rezultatov naše študije z ustreznimi rezultati predhodnih študij.

2.2 Razprava o rezultatih, pridobljenih vzdolž navpičnega prereza hladilnika

Preglednica 3 vsebuje pregled meritev "motenj v hladilniku", pridobljenih v času petletne raziskave.

Preglednica 3 vsebuje povprečja »motenj v hladilniku« v času petletne študije sušilnice. Podatki nazorno kažejo, da se je temperatura zrnja v hladilniku znižala, pa tudi, da se je zrnje med postopkom ohlajanja dodatno navlažilo, namesto da bi izgubilo del svoje vlažnosti. Količino vlage,

The warm grain, after the process of drying, is both cooled and additionally dried in the cooler by 1.5% to 2.0%. However, when the processes of exchange of energy and matter are disturbed, and the grain in the cooler acquires moisture, "a cooler disturbance" occurred.

It was observed that some dryers dry the grain unevenly along the horizontal cut of the tower, so the grain moisture in some samples at the exit of the dryer differs from the overall sample, which does not result from the uneven drying of some hybrids because of their morphology, or unevenness in drying as a result of different input grain moisture, as noticed by Martins and Stroshine, (1987) [4] and Bratko, (1990) [10]. This phenomenon (the unusual behaviour of the corn grain during storage) can be explained based on the sorption isotherm common to cereal. The grain that became moist again after drying changes its sorption isotherm. This change occurs as result of irreversible changes in the grain structure, which results in hysteresis, producing the moisture difference of 1.5–2.0%.

All these changes actually result from bad construction of the tower of the dryer and the transporting elements. As far as we are aware, similar research has not so far been conducted, so we were unable to compare the results from this study with the relevant results from the previous studies.

2.2 Results and discussion based on measurements from the vertical cut of the cooler

Table 3 contains a chart of measurements of "cooler disturbances" obtained during the five-year study.

Table 3 contains averages of the "cooler disturbances" during the five-year period of the study of the dryers. The data clearly indicate that the grain temperature in the cooler decreased, but the data also indicate that the grain acquired additional moisture during the process of cooling, instead of losing an additional

Preglednica 3. *Povprečja "motenj v hladilniku" za čas petletnega študija sušilnice*
Table 3. *"Cooler disturbance" averages in the five-year study of dryers*

Leto raziskave Year of research	M_1 (kg/h)	M_2 (kg/h)	w_1 (%)	θ_1 (°C)	w_{HU} (%)	θ_{HU} (°C)	w_{HI} (%)	θ_{HI} (°C)	w_2 (%)	θ_2 (°C)	t_0 (°C)	φ_0 (°C)
1	24.937	20.508	31,71	37,45	10,58	75,82	11,23	27,19	12,90	21,1	23,0	62,70
2	42.832	36.200	26,37	18,67	10,81	46,75	12,04	18,79	12,88	18,67	5,5	92,5
3	21.522	17.953	29,32	20,24	10,10	73,60	11,73	27,65	11,78	27,20	15,5	74,3
4	27.160	21.996	34,45	14,50	12,94	48,00	14,28	4,40	14,34	12,20	3,2	80,6
5	41.405	33.330	33,88	10,0	12,33	53,70	13,40	20,70	12,74	21,18	-1,0	92,5

ki jo zrnje absorbira v hladilniku, lahko izračunamo na podlagi razlike vsebnosti vlage v zrnju ob vhodu v hladilnik in izhodu iz hladilnika; ta razlika pa je posledica nepravilnega vodenja osuševalnega postopka. Preglednica 4 vsebuje podatke, ki kažejo izgube ugotovljene v petletnem obdobju raziskave na sušilnih napravah. Preglednica pokaže, da je do največje izgube (Δw, kg/dan) prišlo v drugem letu raziskave (-20163,9 kg/dan), najmanjšo izgubo pa smo opazili v zadnjem letu raziskave (-3740,9 kg/dan). Poleg zmanjšane zmogljivosti sušilnice, vključene v raziskavo, smo ugotovili tudi povečano porabo goriva. Preglednica 5 vsebuje podatke o urnem povečanju porabe goriva, pa tudi o povečanju stroškov, ki so ga povzročile "motnje v hladilniku".

Za osušitev 100 kilogramov koruznega zrnja je potrebno 3,5 kilogramov goriva, čigar trenutna cena na Hrvaškem je €0,73 za liter, oziroma €0,93 za kg [13]. Podatki v preglednici 5 kažejo, da je do največje finančne izgube prišlo v drugem letu raziskave, torej v letu največjih »motenj v hladilniku«. To je povsem razumljivo, saj zmnožek povečane izgube in cene goriva pokaže tudi povečano finančno izgubo.

amount of moisture. The amount of moisture the grain absorbs in the cooler can be calculated from the difference in the corn-grain moisture content at the entrance to the cooler and at the exit of the cooler; this difference is the consequence of irregular management of the drying process. Table 4 contains data showing the losses determined during the five-year period of the research on the drying facilities. The table indicates that the biggest loss (Δw, kg/day) occurred during the second year of the study (-20163,9 kg/day), whereas the smallest loss was observed in the final year of the study (-3740,9 kg/day). As well as a capacity decrease for the dryers included in this research, the fuel consumption was found to increase. Table 5 contains data on the increased hourly fuel consumption, as well as on the higher costs resulting from "cooler disturbances".

Drying 100 kilograms of corn requires 3.5 kilograms of fuel. This fuel is currently priced at €0.73/l in Croatia, i.e., €0.93/kg [13]. The data in table 5 indicate that the biggest financial loss occurred in the second year of the study, in the same year that the "cooler disturbance" was the largest. This can be easily explained, the greater loss multiplied by the price of fuel results in a greater financial loss.

Preglednica 4. *Količina absorbirane vode v koruznem zrnju v času ohlajanja*
Table 4. *Amount of re-hydrated water in the corn grain during the cooling process*

Leto raziskave Year of research	**Δw_h (%)**	**Δw (kg/h)**	**Δw (kg/day)**
1	-0,65	-532,08	-12,769,9
2	-1,23	-840,16	-20,163,9
3	-1,63	-335,49	-8,051,8
4	-1,34	-353,71	-8,489,0
5	-1,07	-155,87	-3,740,9

Preglednica 5. *Poraba goriva (izgube), prikazana s količinami in stroški, ki so posledica rehidracije koruznega zrnja v času ohlajanja*
Table 5. *Fuel consumption (losses), shown with the quantities and costs resulting from corn-grain rehydration during the cooling process*

Leto raziskave Year of research	**Povečana poraba goriva / Increased fuel consumption**			
	Količine / Quantities		**Stroški / Costs**	
	(kg/h)	**(kg/day)**	**(€/h)**	**(€/day)**
1	18,62	446,9	17,76	423,18
2	29,41	705,9	27,85	668,43
3	11,74	281,8	11,12	266,84
4	12,38	297,1	11,72	281,33
5	5,46	131,0	5,17	124,05

Če si predstavljamo, da zunanji zrak ohlaja koruzno zrnje, potem razumemo, da je celotna površina zrnja mejna plast, na kateri se tlak vodne pare stabilizira. Na to mejno plast in stabiliziran tlak vplivajo značilnosti notranjega dela zrnja, ki mora vrhnjo plast oskrbeti z zadostno količino vode, kadar ta izpareva s površine. Toda pot vode iz notranjosti proti površini je težka, zato mejna plast zrnja ne dobiva zadovoljive oskrbe z vodo iz notranjosti, saj se voda giblje skozi celične membrane s pomočjo kapilarnih sil, termodifuzije in osmoze. Površina zrnja je zato slabo oskrbljena z vodo, kar pomeni, da je vlaga na površini zrnja nižja od vlage v njegovem jedru.

Tako je, na primer, vsebnost vlage v jedru zrnja 14% pri temperaturi 25°C in tlaku vodne pare 2216 Pa. Hkrati pa je vlažnost mejne plasti 10%, njena temperatura 15°C, tlak vodne pare pa zgolj 618 Pa. Kadar je temperatura zunanjega zraka 10°C, njegova vlažnost 90% in je tlak vodne pare v zraku 1104 Pa, voda iz zraka preide na zrnje zaradi razlike med tlakom zrnja in tlakom zraka, kar pomeni, da se zrnje navlaži.

Če celotni postopek opazujemo na diagramu *h-x*, opazimo, da ima zrak, ki zapušča hladilnik, manjšo vsebnost vode kakor zunanji zrak ter da je absolutna vsebnost vlage v zraku večja ob vhodu v sušilnico kakor ob izhodu iz nje. Zanimivo je dejstvo, da je zrak, ki zapušča hladilnik, toplejši od zraka, ki vstopa v hladilnik. Osuševanje zraka je povzročilo zmanjšanje njegove specifične toplotne kapacitete in tako je, kljub prenosu energije v postopku kondenzacije vode na zrnju, preostala energija povečala temperaturo zraka. Če primerjamo rezultate, ki smo jih dosegli med petletno raziskavo, z rezultati, ki so jih pridobili drugi avtorji, je očitno, da so naši izsledki primerljivi z doslej objavljenimi tovrstnimi podatki.

If we think of a corn grain being cooled by the surrounding air, then the whole of its surface can be thought of as a boundary layer where the water vapour pressure stabilizes. This boundary layer and the stabilized pressure are influenced by the properties of the inner part of the grain, which has to supply the surface with a sufficient amount of water, if water evaporates from the surface. However, movement of the water from the inner part towards the surface is difficult, and so the boundary layer does not have an adequate supply of water from the inner part because water moves through the cell membranes by means of capillary forces, thermo-diffusion and osmosis. The surface of the grain is, as a result, poorly supplied with water, which means that the grain's moisture on the surface is lower than the moisture in the centre.

For instance, the centre of the grain has a moisture content of 14% when the temperature is 25ºC and the water vapour pressure is 2216 Pa. At the same time the boundary layer's moisture content is 10%, with a temperature of 15ºC and a water vapour pressure of only 618 Pa. If the surrounding air temperature is 10ºC and the air humidity is 90% with the water vapour pressure in the air equal to 1104 Pa, water from the air will move into the grain because of the pressure difference between the grain and the air, i.e., the grain will get moist.

If the whole process is observed on an h-x diagram we can see that the air leaving the cooler has lower water content than the surrounding air, and the absolute air humidity content is higher at the entrance to the dryer than at the exit. It is interesting to note that the air exiting the cooler is warmer than the air entering the cooler. Drying the air reduced its specific warmth capacity, so although the energy was transferred in the process of water condensation on the grain, the remaining energy raised the air temperature. If we compare the results obtained in the five-year study with the results obtained by other authors, it is clear that the results are significant in terms of the results from other references.

3 SKLEP

Na podlagi petletne raziskave "motenj v hladilniku" navpične gravitacijske sušilnice, lahko naredimo naslednje sklepe:

Pojav "motenj" v hladilniku moramo opazovati na dva načina:

- vzdolž navpičnega prereza sušilnice,
- vzdolž vodoravnega prereza sušilnice.

1. "Motnje v hladilniku" lahko definiramo kot pojav v predelu za ohlajevanje, ki povzroča, da se osušeno zrnje navlaži, oziroma rehidrira med

3 CONCLUSION

Based on a five-year study of "cooler disturbance" in a vertical gravity dryer the following conclusions can be drawn:

The phenomenon of "cooler disturbance" must be observed in two ways:

- along the vertical cut of the dryer,
- along the horizontal cut of the dryer.

1. "Cooler disturbance" can be defined as a phenomenon in the cooling zone resulting in the dried grain becoming moister or re-hydrated in the dryer

postopkom ohlajevanja v sušilnici.

2. Pojav "motenj v hladilniku" vzdolž vodoravnega prereza sušilnice povzroča širok razpon vsebnosti vlage v koruznem zrnju, kar nadalje povzroča kvarjenje zrnja v času skladiščenja in znižanje njegove hranljivosti.
3. "Motnje v hladilniku" vzdolž navpičnega prereza sušilnice povzročajo zmanjšanje kapacitete sušilnice in povečanje porabe goriva. Posledica tega pa je zmanjšana finančna učinkovitost sušilnice.
4. "Motnjam v hladilniku" vzdolž vodoravnega prereza sušilnice se lahko izognemo s pravilno gradnjo stolpa sušilnice, ki naj ima primerno velikost pokrovov, primerno hitrost zraka in pravilno zgrajeno in prilagojeno krivino izpustne enote ob izhodu iz sušilnice.
5. "Motnjam v hladilniku" vzdolž navpičnega prereza sušilnice se lahko izognemo s pravilnim uravnavanjem delovanja sušilnice, tako da je vlažnost koruznega zrnja ob vhodu v sušilnico večja od vlažnosti pri higroskopični izravnavi ter da je razlika med tlaki v komorah sušilnice pravilno uravnana.

during the process of cooling.

2. The phenomenon of "cooler disturbance" along the horizontal cut of the dryer results in a wide range of corn-grain moisture contents, which finally results in spoiling of the grain during storage and a reduction in its nutritious properties.
3. "Cooler disturbance" along the vertical cut of the dryer results in a reduction of the dryer's capacity and an increased fuel consumption. As a result, the financial effectiveness of the dryer is reduced.
4. "Cooler disturbance" along the horizontal cut of the dryer can be avoided by correctly constructing the dryer tower, having a suitable size for the tops, an appropriate air speed, as well as a correctly constructed and adjusted concave discharge at the exit of the dryer.
5. The phenomenon of "cooler disturbance" along the vertical cut of the dryer can be avoided by regular adjustment of the dryer's operation, so that the corn grains have a higher humidity than hygroscopic balance when entering the cooler and that the pressure difference between the pressure of the chambers of the dryer is correctly adjusted.

4 LITERATURA
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