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Influence of the moistening and drying of wheat grain on its hardness

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A b s t r a c t. The influence of the moistening and drying of two cultivars of wheat grain (Roma and Igna) on changes in the hardness index (HI) was determined. Samples of grain with an initial moisture of 11.5%, were wetted to a moisture ranging from 15.0 to 37.6%. When drying the grain, air temperatures ranging from 26 to 90°C were applied. The results of the studies showed that an increase in drying temperatures influenced the decrease of grain hardness. The HI decreases were largest in grain which had been moistened to a medium degree and then dried. The influence of moistening on grain hardness was bidirectional. At the lower range of moisture content (from 15.0 to 29.2%), this treatment influenced the grain endosperm structure destructively, weakening its hardness while the higher range of increase in the grain moisture (from 29.2 to 37.6%) affected of the grain hardness beneficially.

K e y w o r d s : wheat grain, moistening, drying, hardness

INTRODUCTION

The hardness of grain is a feature formed during the wheat vegetation period, especially during the grain development, under genotype and environmental factors [1-4,6]. However, changes in this feature do not cease the moment the grain has ripened. With delaying harvesting, the weather conditions cause alternate moistening and drying of mature grain contributing to the gradual decrease in hardness [9]. After the harvest, the grain can also be subjected to moistening and drying processes, e.g., before storage or milling [13].

The mechanism of influence of the moistening process on the decrease of grain hardness in the pre-harvest period is particularly well documented. Grain is moistened by rain or dew and at the same time, cracks form in the endosperm [2]. Cracking results from the quick soaking up of liquid by the external layers of the endosperm which expand and split the more deeply laid non-moistened layers. Damage to the endosperm occurring in this manner loosens its structure and contributes simultaneously to a decrease in grain hardness. The negative effects of the moistening of the grain have been also confirmed in laboratory investigations [10,16,19].

Investigative studies on the influence of the drying process on changes in the hardness of the wheat grain are less numerous. Studies by Niewczas and Woźniak [11] as well as Woźniak and Styk [18] showed that the number of damaged grains (with endosperm cracks) was distinctly higher when higher air temperatures were applied. Similar effects were obtained under microwave drying by lengthening the duration of this process [12]. Regardless of the manner of drying applied, grain hardness decreased in proportion to the duration of the drying. Moreover, the changes in hardness were closely connected with the degree of endosperm damage caused by the drying process [17].

The investigations cited above show that intensive moistening and drying processes cause essential structural changes in the endosperm of wheat grain, a measurable symptom of which is a decrease in its hardness. However, these results came from experiments, in which the intensity of only one of the processes studied, i.e., the moistening or drying, was different. The second process was carried out in stable conditions. It was not possible, therefore, to compare both of these processes in terms of their effect and so further investigation is necessary in order to describe the dependence of grain hardness on both these processes simultaneously.

Taking into consideration the above-mentioned premise, an experiment has been designed in which the intensity of moistening can be changed independently of the intensity of the drying process. The degree of the moistening of the grain

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throughout the process was differentiated by the quantity of water used in it and the drying rate was regulated by the temperature of the air. Determining the influence of the conditions of this experiment on the course of changes in grain hardness is the subject of the present article.

MATERIALS AND METHODS

Studies were conducted on the wheat grain of the following two cultivars: Roma (the winter form) and Igna (the spring form), differing only in the hardness of the grain endosperm. The Roma cultivar was characterised by its low hardness index (HI = 39.4), while the Igna cultivar was characterised by a high index (HI = 74.2). According to the Perten Instruments classification [15], the cultivars studied were assigned numbers according to class: 3 (mix) and 1 (hard), respectively. By limiting the number of cultivars studied to two, most of the effort was concentrated on recognising the mechanism of the moistening and drying processes on the mechanical properties of the individual grains rather than on showing the different reactions of individual wheat cultivars.

In the laboratory experiment, the moisture of the grain and the drying temperature were different. Grain samples, with an initial moisture of 11.5%, were moistened to a moisture of 15, 18.3, 24.1, 29.2, 33.6 and 37.5%. Accordingly, 60 g samples of grain together with distilled water (respectively, 2.5, 5, 10, 15, 20 and 25 g) were placed in cans of 0.5 dm^3 capacity and left for 24 h in a laboratory stirrer (10 rpm). Moistening took place in the constant temperature of the surroundings (22.5 ± 0.5°C).

When fully moistened, the grain samples were spread (0.5 g of dry basis cm^{-2}) on sieves and placed in a Brabender laboratory dryer, type 890 100. Grain undergoing drying was held at the following air temperatures: 26°C (minimum for this type of dryer and surrounding conditions), 40°C and successive temperatures with 5°C steps to 90°C. The drying process was interrupted when the moisture of the grain achieved 11.5% (the initial moisture). The duration was established on the basis of the drying curves appointed for each separately studied cultivar (Fig. 1). The drying time, in relation to grain moisture and temperature, ranged from 20 min to about 49 h (at a drying temperature of 26°C). After the

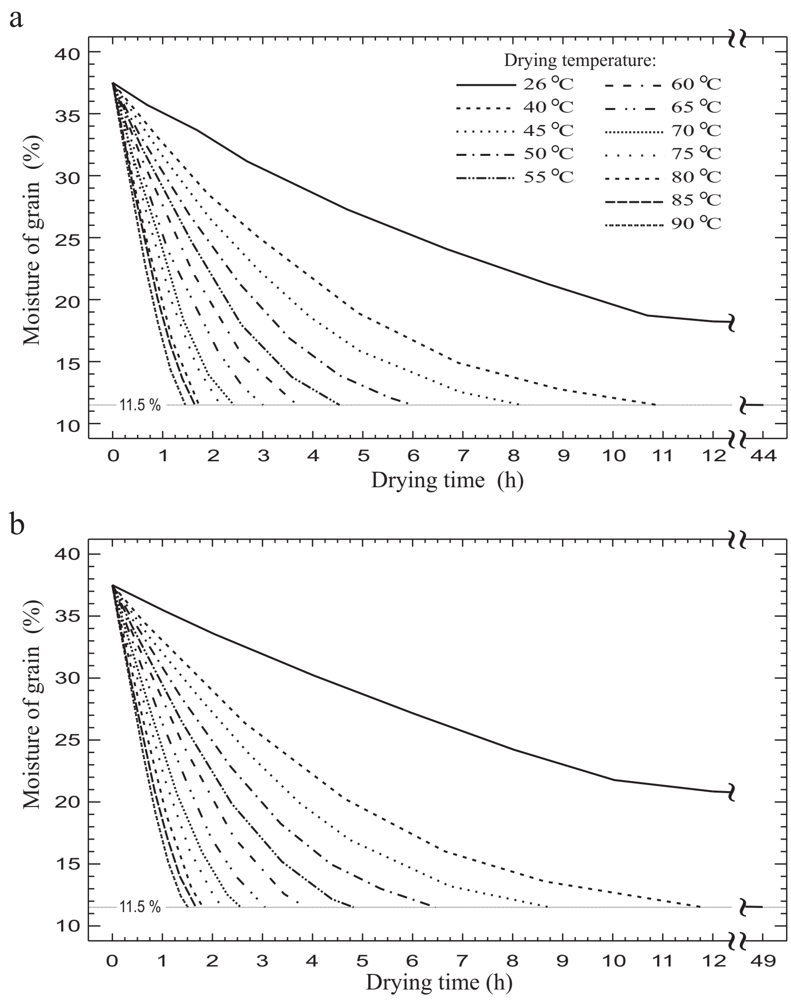

Fig. 1. Drying curves of wheat grain for cultivars Roma (a) and Igna (b).

drying had finished, the grain samples were cooled in an ambient temperature (22.5°C), and then stored for 3 months.

Changes in the activity of α-amylase in the grain were estimated by measuring the falling number value, according to standard ICC No. 107/1. The hardness index (HI) of individual grains was measured by the SKCS 4100 device, Perten Instrument AB [7,14]. Each HI measurement result was obtained by evaluating 100 randomly selected grains. The measurements were executed in 3 repetitions. Within the statistical analysis of results, 95% confidence intervals for the means (LSD) were calculated. The LSD values were used to determine the drying temperatures permissible, which did not cause any significant changes in the HI values referred to where the grain was dried under 26°C.

In order to characterise the interrelation of the hardness index with the moisture of the grain being dried (M) and the drying temperature (T), a model equation of non-linear regression was built which possibly described the changes in the HI most precisely. The degree of its suitability for measuring data was estimated by determining the coefficients of determination (R^2).

RESULTS

The drying process was conducted on grain samples with widely differing moisture contents as a result of wetting. It is obvious that one possible effect of the moistening of grain, especially wetting to any significant degree, is the increased activity of the amylolytic enzymes. For a characterisation of these changes, the dependence of the falling number on the grain moisture content and the drying temperature is presented in Fig. 2. Significant decreases in the falling number appeared in grain moistening at a moisture ranging from 29.2 to 37.5%; meanwhile its minimum values ranged considerably above the limit value (150 s), which is that usually assumed for sprouting grain. Moreover, when moisturising to 37.5% , the high amounts of water used in the process cut off the air to the grain and inhibit the already stirred activity of the amylolytic enzymes. The Roma cultivar, in comparison with the Igna cultivar, differed in the quicker slow-down of the synthesis of the enzymes on account of the lack of access to air. The increase in temperature during the drying of the grain provoked a slight decrease in the activity of these enzymes.

While drying the grain the considerably larger influence of the temperature on changes in the hardness index was noted (Fig. 3). The values of this index decreased under increasing drying temperature quite steadily. However, the tempo of these decreases depended to a large degree on the moisture in the grain being dried. Listed in Table 1 are the permissible values of the drying temperature indicating that at the lowest grain moisture (15%) the range of HI changes was the smallest and was generally speaking within the confidence interval (LSD). While the largest hardness decreases when drying, temperature rises from 26 to 90°C, occurred when the grain was moistened moderately. For the Roma variety, maximum decreases did not exceed 10 units of HI whereas for the Igna variety they came to almost 13 units of HI.

The degree of grain moistening affected HI changes non-linearly (Fig. 3). The course of the dependence of the HI on the moisture of grain being dried was characterized by the occurrence of a certain minimum value. Initially, the increase in moisture from 15.0 to 18.3, and 24.1% caused considerable decreases in the HI values. At 29.2% moisture, a decreasing tendency was reversed while a further increase of moisture to 37.5% contributed to a gradual increase in the HI values. The range of HI changes described, increased

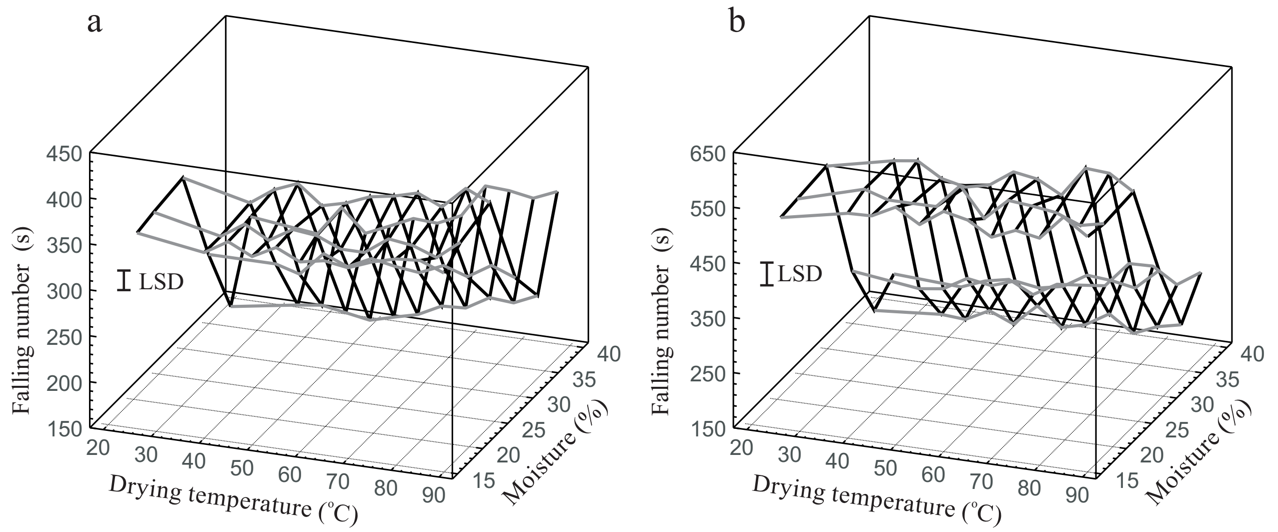

Fig. 2. Effect of drying temperature and moisture of wheat grain of cultivars Roma (a) and Igna (b) on falling number.

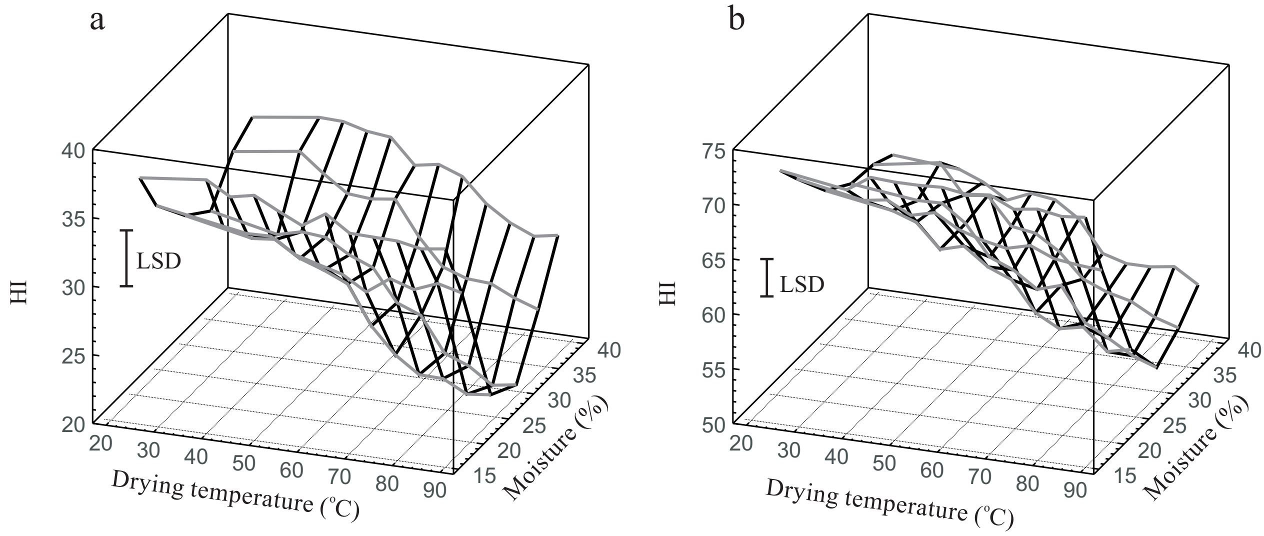

Fig. 3. Effect of drying temperature and moisture of wheat grain of cultivars Roma (a) and Igna (b) on hardness index (HI).

Table 1. Permissible drying temperature values which do not cause changes to the HI in relation to grain moisture and wheat cultivars (°C)

Wheat cultivars	Grain moisture (%)					
	15.0	18.3	24.1	29.2	33.6	37.5
Roma	-[a]	-	60	60	60	75
Igna	-	65	45	50	50	65

[a] - lack of significant changes in HI values.

proportionally to the drying temperature used. At 90°C temperature, the maximum decreases of hardness under moistening amounted to 15 and 20 units of HI, respectively for both the Roma and Igna cultivars. For comparison, the maximum hardness increases due to higher moistening were clearly lower and amounted respectively to 8 and 4 of units of HI, whereas minimum HI value were noted when drying the grain with 29.2% of moisture, without regard to either the cultivar of the wheat or the drying temperature.

These results prove that the process of moistening the grain at the lower range causes considerably larger changes in grain hardness than does the process of drying along the whole range of available temperatures. Moreover the negative effects of lower degrees of moistening, apparent in the mechanical damage of the grain endosperm, can only be partly repaired under higher degrees of moistening which contributes to a strengthening of the endosperm structure (HI).

The character of changes in the index hardness (HI) when drying the moistened grain is described by means of the following equation of non-linear regression:

$$HI(M, T) = a + b \cdot T (M - c)^2 + d \cdot T, \quad [-],$$

where: M – moisture of grain subjected to drying (%), T – drying temperature (°C), a, b, c and d – equation parameters.

Values of the parameters of the regression equation have a physical sense and can be easily interpreted (Table 2). Parameter a means the HI value, which the grain would possess when dried at a temperature of 0°C. In turn parameter b expresses the size of the HI change under the unit increase of grain moisture and drying temperature. A more valuable parameter of equation is c. It expresses the amount of moisture in the grain at which drying causes minimum values of HI. In other words, the c value is critical moisture, below which moistening causes weakness, while moisture above this value contributes to a strengthening of grain hardness. The last parameter of the proposed equation (d) characterizes the size of the changes to which the hardness is subjected under an increase of unit drying temperature. As can be seen from data in Table 2, the wheat cultivars studied differed significantly with respect to all parameters. The a values were almost identical with the values for the grain of

T a b l e 2. Equation parameter values of the regression of HI for the dried grain of wheat cultivars studied

Wheat cultivar	Equation parameters	Parameter unit	Parameter value	Standard error	Determination coefficient
Roma	a	-	38.36	0.46	0.9454
	b	$\%^{-2} \cdot °C^{-1}$	$1064 \cdot 10^{-6}$	$41 \cdot 10^{-6}$	
	c	%	27.80	0.14	
	d	$°C^{-1}$	-0.1968	0.0075	
Igna	a	-	72.55	0.43	0.9719
	b	$\%^{-2} \cdot °C^{-1}$	$856 \cdot 10^{-6}$	$39 \cdot 10^{-6}$	
	c	%	31.33	0.27	
	d	$°C^{-1}$	-0.2187	0.0069	

both cultivars not subjected to moistening and drying (control). The grain of the Roma cultivar was more sensitive to the simultaneous action of the processes of moistening and drying (*b* value), while the grain of the Igna cultivar responded more strongly to increasing drying temperatures (*d* value).

The results presented in Fig. 4. show that the proposed model equation of regression of the index hardness is quite adequate for measuring data and is able to indicate simultaneously the great degree of the practicality of this regression model in predicting the changes in grain hardness under the processes of moistening and drying. The model proposed can considerably facilitate understanding of the way in which the processes of moistening and drying affect grain hardness.

DISCUSSION

The processes of moistening and drying grain modify the biochemical, structural and mechanical properties of its endosperms. In the present investigations, the main effort was focused on studying the biochemical (the activity of amylolytic enzymes) and mechanical (grain hardness) changes. It has been stated that the moistening treatment used increased enzyme activity to permissible levels, and did not cause the grain to sprout. The authors' earlier investigations [8] showed that at the every moment sprouting appeared, mechanical weakening of the endosperm grain structure began. In these investigations gentle moistening was applied by placing grains between two layers of blotting paper soaked at different degrees over long period (72 h). Grain thus moistened, from moisture of 11.5 to over 25%, did not distinguish the reduced hardness (HI) in comparison to grain not subjected to this treatment. These facts indicate the lesser significance of the degree of moisture in weakening the hardness measured by the increment of the grain

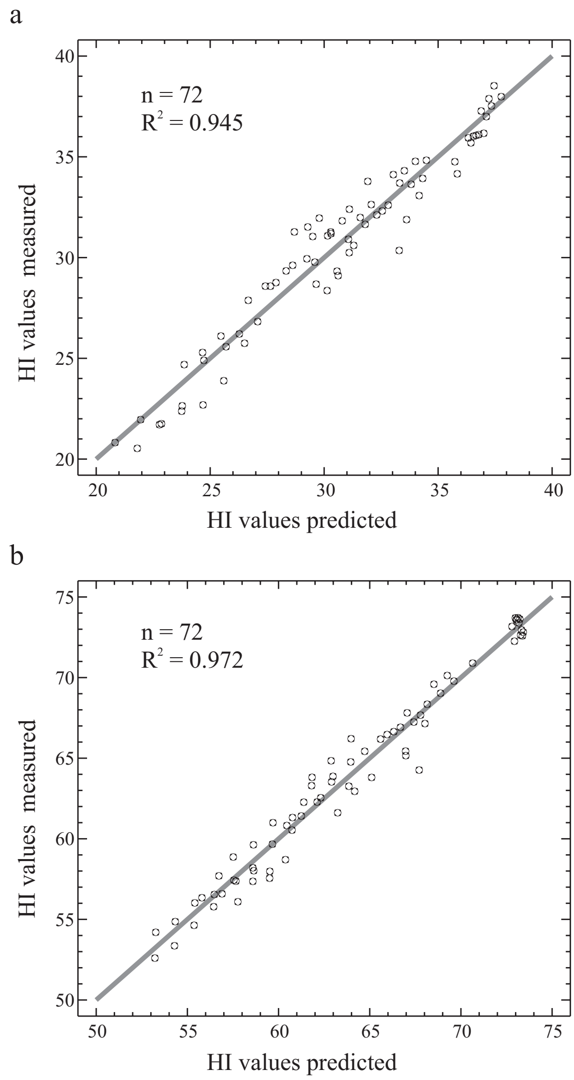

Fig. 4. Fitting of the model equation of regression of hardness index (HI) for dried wheat grain of cultivars Roma (a) and Igna (b).

moisture, whereas the decisive factor seems to be the rate of moistening, expressed by the size of the increment of moisture per time unit, as well as by the size of the gradient of moisture between the external and internal layers of the endosperm. The numerous investigations of the different authors also point to the essential role played by these factors as being the main sources of the mechanical destruction of the endosperm [2,11,16,18,19].

The moistening treatment applied in the present investigations requires the whole of the grain surface to come into direct contact with water which will ensure that the water is thoroughly absorbed while simultaneously increasing the gradient of the moisture of the endosperm. Taking as a basis the moment of the appearance of the maximum HI decrease, the conclusion may be drawn that the largest increments of this gradient took place when the degree of grain moistening increased from a moisture of 18.3 to 24.1%. Lower moistening also caused significant decreases of HI. This means that even a small amount of water, moistening the grain surface, can cause structural changes to its endosperm. Similar conclusions can also be inferred from the Rentgenographic investigations on mechanical damage to grain while undergoing moistening [11,18,19]. They indicate that the largest increase in the number of cracks in the endosperm takes place after the first hour of moistening. The tempo of this increase diminishes perceptibly with continuing wetting.

The results of the present investigations showed that the moistening process, when undertaken over a longer period (24 h) can – apart from destroying the endosperm – contribute to the partial reconstruction of its original structure. Initially, the moistening process always and increasingly destroys the endosperm until the moisture gradient in the endosperm reaches a maximum (Fig. 5). This second and reconstructive action of the moistening process begins much later than the first and destructive action. It is characterised by weakening the gradient of moisture resulting from the penetration of water to ever deeper layers within the endosperm. The swollen tissues of the endosperm bound together – which occurred during destruction – crack open and reconstruct the original structure to some degree. Reconstruction intensifies with the increase in the degree of moistening (Fig. 5). Therefore the final state of the structure of the endosperm of the grain which has been subjected to moistening is the sum of both distructive and reconstructive effects.

The investigations conducted showed additionally that the destructive effects take precedence over the reconstructive ones, even at the highest degrees of grain moistening. This means that the reconstructed structure of the endosperm is always somewhat less hard in comparison to its original structure. The degree of its reconstruction depends however on the texture of the endosperm, conditioned mainly by the genotype of the wheat cultivar. Roma grain, possessing a softer endosperm structure than Igna grain, was more susceptible to the reconstructive action of the moistening process and simultaneously – but to a smaller degree – was subjected to destructive action under this process.

The drying temperature of moistened grain also influenced the magnitude of the destruction and reconstruction. Together with an increase in drying temperature both kinds of effects were intensified. This means that intensive drying on the one hand causes additional damage to the endosperm by softening it more. On the other hand, at higher degrees of moistening, the cracks in the endosperm seem to disappear, the effect of which is a noticeable increase in hardness. This was observed particularly in the case of the cultivar with the endosperm of a softer grain (Roma). However, the grain of the cultivar with the harder endosperm (Igna) reacted less favourably to the reconstructive effects of drying.

No investigations from other authors are available that would confirm the existence of the reconstructive effects of the moistening and drying processes on the endosperm of wheat grain. The results of the investigations cited [10,11, 16-19] came from experiments in which different moistening techniques were applied, primarily over shorter periods

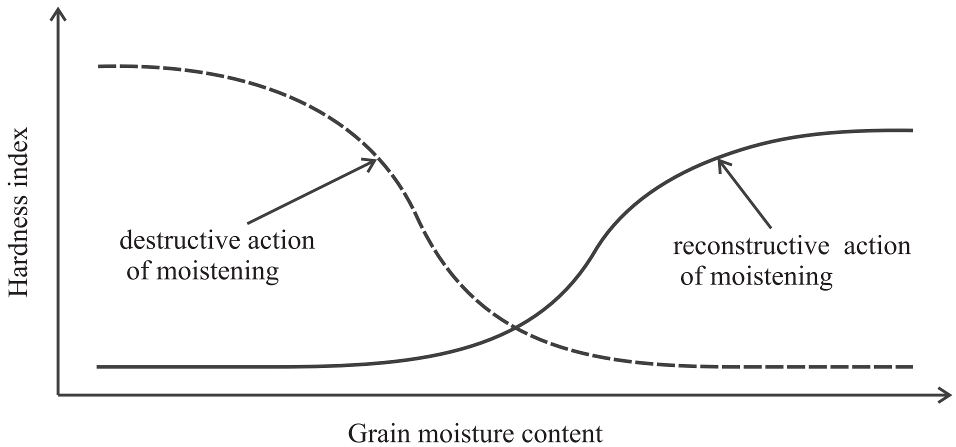

Fig. 5. Proposed model of the inter-relation of grain hardness to the destructive and reconstructive actions of moistening treatment.

and with narrower ranges in the degrees of the moistening of the grain in order that the conclusions of those investigations would exclusively contain a description of the effects of the destruction. However, as shown in the present paper, where moistening leads to the tissues of the endosperm of the grain being very highly moisturised and where this is maintained for a sufficiently long period of time, the phenomenon of reconstruction also takes place. Suffice it to say, that further investigations are necessary in order to verify the reconstructive nature of the processes of moistening and drying grain.

CONCLUSIONS

1. The conditions employed in the moistening and drying of wheat grain have a huge impact on the different mechanical properties of individual grains as estimated by the hardness index (HI). The ranges in the differences of the HI value were contained in intervals from 21 to 39 and from 53 to 74 [-], for the Roma and Igna cultivars, respectively.

2. The drying temperature reduced grain hardness in one direction only. The largest decreases in hardness, as a result of temperature rises from 26 to 90°C, came to 10 and 13 units of HI, for the Roma and Igna cultivars, respectively. Grain moderately moistened was particularly susceptible to these changes.

3. In contrast to the drying temperature, the degree in which the grain underwent moistening had a more complicated influence on the shaping of the hardness of the grain. Moistening of the grain within the range from 15.0 to 29.2%, caused a gradual fall in the hardness index. Hardness reductions deepened with an increase in drying temperature. Maximum decreases amounted to 15 and 20 units of HI, for the Roma and Igna cultivars, respectively.

4. The reverse action of the moistening process on the hardness index took place where the grain moisture ranged from 29.2 to 37.5%. The increase in the degree of moistening in this range influenced the increase of HI gradually and proportionally to the drying temperature. The maximum increases of hardness amounted to 8 and 4 units of HI, for the Roma and Igna cultivars, respectively.

5. The dependences described show that moistening and drying processes at lower ranges of grain moisture caused mechanical damage to the structure of the grain endosperm and as a result of this, hardness decreases considerably. In turn, moistening and drying undertaken at higher ranges of grain moisture encourage profitable structural changes in the endosperm, which compensate in part for the destructive effects of these processes, the result of which is a significant increase in grain hardness.

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