JMBFS

Journal of Microbiology, Biotechnology and Food Sciences

International peer-reviewed scientific online journal

Published by Faculty of Biotechnology and Food Sciences

CHANGES IN THE CONTENT OF β -GLUCANS DURING THE MALTING PROCESS

Miriam Solgajová, Štefan Dráb, Ján Mareček*

Address(es): Ing. Miriam Solgajová, PhD.
Institute of Food Sciences, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic.

*Corresponding author: miriam.solgajova@uniag.sk

https://doi.org/10.55251/jmbfs.6001

ARTICLE INFO

Received 25. 3. 2022
Revised 8. 6. 2022
Accepted 15. 6. 2022
Published 1. 10. 2022

Regular article

OPEN ACCESS

ABSTRACT

β-glucans are non-starch polysaccharides found in the cell walls of endosperm. A high content of these polysaccharides in barley grain causes inadequate grain modification during the malting process, due to the fact that β-glucans inhibit enzymes to enter the cell walls of the endosperm. During malting process, barley germinates and produces hydrolytic enzymes that de-structure the endosperm, making the grains soft and friable. During mashing process, β-glucans lower the brewing yield and moreover they cause turbidity of brewed beer. The goal of this work was to analyse the degradation process of β-glucan content during the malting process. Two methods such as the enzymatic method and the flow injection analysis method were used to analyse the content of β-glucan in barley grain, in germinated grain as well as in the malt and in wort. Results showed the decrease of β-glucan content from barley to wort, β-glucans were degraded by 97 %. All evaluated varieties fulfilled requirements for β-glucan content in wort, values were lower than 250 $mg.dm^{-3}$. Moreover, a positive significant correlation among the content of β-glucan in malt and the viscosity of worth was found but on the other hand significant correlation among the β-glucan content in wort and the viscosity was not proven. Statistical significant correlation was proven among the starch content in barley grain and friability of malted grain.

Keywords: malting barley, malting, malt, β-glucan degradation

INTRODUCTION

Barley is the primary cereal used in the production of malt worldwide. It is the basic component of conventional beer, contributing to its aroma, flavour and body (**Cimini *et al.*, 2017**). Barley has a high level (up to 6% average) of β-glucan which is water-soluble polysaccharide considered as soluble dietary fiber (**Goudar *et al.*, 2020**). β-glucans are the main components of the cell walls of the endosperm however other constituents such as arabinoxylan, cellulose, glucomannan, protein and phenolic compounds are also present (**Beer *et al.*, 1997; Holtekjølen *et al.*, 2006; Marconi *et al.*, 2014**). β-glucan is a linear chain of the β-glucopyranosyl unit; about 70% is linked (1 → 4) and about 30% (1 → 3) linkage (**Izydorczyk and Dexter, 2008; Sharma and Gujral, 2014**). The β-glucan content ranges from 2 to 6 $g.100\ g^{-1}$ in malt and barley cell walls, and from about 0 to 3.95 $g.l^{-1}$ (with an average content of 100–300 $mg.l^{-1}$) in beer. If malt contains a high proportion of β-glucans or is poorly modified, or the brewing process employs a significant proportion of unmalted barley, the β-glucan fraction can survives unmodified into the beer due, in part, to the temperature-labile nature of native malt β-glucanases (active up to a maximum temperature of 60 °C), (**Izydorczyk and Dexter, 2008; Habschied *et al.*, 2020**)

High β-glucan levels have generally been associated with many brewing problems, such as low extract yields (**Habschied *et al.*, 2020)** high wort and beer viscosity, slow wort separation and beer filtration rate, especially in the case of membrane filtration, as well as a reduced beer colloidal stability (**Cimini and Moresi, 2014**). Barley fibre and particularly β-glucans are not desirable for the brewing and malting industries. They increase density of malt or beer, prolong filtration, and cause haze and sediments in beer (**Newman and Newman, 2008**). Therefore, the malting industry prefers barley with lower levels of β-glucan (**Runavot *et al.*, 2011**).

Many of such brewing problems may be minimized by resorting to selected barley varieties (**Cimini *et al.*, 2017**). Barley is one of the most genetically diverse cereals, its amylose and β-glucan contents are primarily under genetic control. Barley genetic diversity provides many opportunities to identify and breed barley varieties for specific end uses, and also fulfill specific requirements by maltsters and brewers (**Briggs, 1998**). Applying improved processing technologies represents another solution. In particular, **Cimini *et al.* (2017)** suggested that the mashing and germination steps can be performed at higher temperatures and/or humidity to enhance the activity of naturally occurring β-glucanases without overstimulating β-glucan solubilase. Addition of exogenous β-glucanases to the mash or beer is a relatively recent option, and its main negative effects are extra operating costs and sometimes ineffectiveness if used in a beer with high turbidity (**Cimini and Moresi, 2015**). On the other hand, the presence of β-glucan gives to barley a status of functional grain and it is associated with various health benefits. β-glucan has been shown beneficial effects for heart patients by reducing blood pressure, lower serum cholesterol and visceral fats (**Behall *et al.*, 2004**).

The aim of this work was to analyze whether the content of β-glucan in barley and malted grain changes during the malting process by using two analytical methods - FIA and enzymatic.

MATERIAL AND METHODS

Materials

Eight two-raw spring malting barley varieties Malz, Kangoo, Overture, Laudis 550, Karmel, Valis, Exalis, Kumran evaluated in this work were grown in locality Veľké Ripňany (southern Slovakia). Evaluated samples of malting barley came from the harvest year 2016. Long-term average temperature for this locality was 9.7 °C, long-term average sum of precipitation was 582 mm and code of soil was brown soil.

Barley varieties with selected malting quality used in the experiment were obtained from two breeders. The varieties were registered in the Slovak Republic in various years and met the requirements for β-glucans content in wort during registration.

Subsequently samples were micro malted in laboratory micro malting plant (Ravoz, Olomouc, Czech Republic) provided by research Institute AgroBioTech at Slovak Agricultural University in Nitra, divided into 3 separate units: steeping, germination and kilning box.

All determinations were carried out according to European Brewery Convention recommended methods **(EBC, 2010)**.

Micro Malting

For laboratory micro malting the standard malting procedure was used according to MEBAK (Middle European Brewing Analysis Commission) 1.5.3 **(MEBAK, 2018)**. Samples of 1 kg from each barley variety were used for malting process. Steeping was conducted in the steeping box. Barley was steeped 2 days at 14 °C, samples were under water for 10 h followed by an air rest, full steeped on water content 46 %. Germinating was conducted in the germinating box. Germination was performed at 14 °C for 3 days to obtain green malt. The kilning process was performed on an electrically heated one-floor kiln, with a gentle and gradual increase in temperature up to the kilning temperature of 80 °C for 4 h. The total time of kilning was 22 hours. Throughout these procedures as steeping and germination process, the samples of 20 g were collected for further analysis.

Methods

The determination of total β-glucan content in barley varieties was conducted in accordance with enzymatic EBC Method 3.11.1, using a commercial assay kit (Megazyme International Ireland, Bray, Ireland) and also according to flow injection analyses EBC Fluorimetric Method 3.10.2. Moreover, determination of total β-glucan content in accordance with Fluorimetric EBC Method 4.16.2 for malt and for malt wort was conducted. The determination of total β-glucan content according to enzymatic EBC Method 4.16.1 for malt and 8.11.1 for malt wort was performed as well.
Determination of barley moisture content (EBC Method 3.2), starch content (EBC Method 3.13) and crude protein content (EBC Method 3.3.1) was performed according to the European Brewery Convention methodology.
Congress worts were prepared according to EBC Method 4.5.1 and the technological parameters such as extract content and saccharification time (EBC 4.5.1), wort colour (EBC 4.7.1), turbidity (EBC 9.29) and wort viscosity (EBC 4.8) were also analysed in the samples. In malted samples the friability (EBC 4.15) and moisture content (EBC 3.2) was determined. Malt and wort analyses were carried out according to the European Brewery Convention methodology **(EBC, 2010).**

Statistical analysis

The data were analysed by one-way repeated measures analysis of variance (ANOVA) and the correlations were analysed by Person's correlation coefficient. A differences were considered statistically significant if $p < 0.05$. The experiment was performed in three replicates.

RESULTS AND DISCUSSION

To increase the brewing yield and efficiency, malts with high extract values, high enzymatic activities, and good modification are essential (**Woonton *et al*., 2005).** In order to achieve malt of optimal quality, barley must meet the strict quality requirements regarding its technological quality.
In this work the total content of β-glucan in monitored barley varieties was determined by using the flow injection analyses (FIA) method and the enzymatic (enz.) method. From the data presented in Table 1, it can be seen that the range of β-glucan concentrations in the tested varieties (3.08 g.100g^{-1} to 4.63 g.100g^{-1}, enz.), (2.37 g.100g^{-1} to 4.67 g.100g^{-1}, FIA) differed. The lowest content of β-glucan recorded variety Laudis, such as 2.37 g.100g^{-1} (FIA method) and 3.08 g.100g^{-1} (enz. method). The highest content of β-glucan recorded variety Overture 4.67 g.100g^{-1} (FIA method) and Karmel variety (4.63 g.100g^{-1}) (enz. method), (Table 1). All barley varieties met the values for β-glucan content in comparison to study reported by **Wang *et al.* (2004)**. Authors reported an average β-glucan content of the eight tested varieties at the amount of 3.8 %. Usually, the content of β-glucan in barley grain ranges from 2 to 8 %. It depends on genetic and environmental factors (**Marconi *et al.*, 2014).** Malting barley should contain as little β-glucan as possible, up to 4 %. β-glucans slow down grain degradation by preventing enzymes from entering endosperm cell walls. They pass throughout the whole process of malting into the beer. This means, the more β-glucans pass into the beer the more turbid brewed beer will be (**Marconi *et al.*, 2014; Habschied *et al.*, 2020)**. Table 1, figure 1 shows the β-glucan degradation in evaluated samples caused by the malting process. In all samples, the β-glucan content decreased due to steeping and germination processes. From the results of enzymatic method, at the end of the steeping process, the lowest content of β-glucan 1.64 g.100g^{-1} was determined in Kangoo variety and the highest 2.31 g.100g^{-1} reached Overture variety (Table 1). The β-glucan content had a decreasing tendency during germination process and at the end of germination process, the Exalis variety reached the lowest content of β-glucan 0.15 g.100g^{-1}, on the other hand the Malz variety contained the highest 0.25 g.100g^{-1} (Table 1). We assume this variable decrease in β-glucan content within individual varieties may be caused due to the different β-glucan content in the barley grain before the malting process and due to different activity of the cytolytic enzyme β-glucosidase. From the results of FIA method, at the end of the steeping process, the lowest amount of β-glucan was found in the Kangoo variety (1.83 g.100g^{-1}) and the highest 3.10 g.100g^{-1} was found in the Kumran variety (Tab 1). At the end of germination process the lowest value was measured in the variety Kumran (0.09 g.100g^{-1}) and the Valis variety had the highest β-glucan content of 0.19 g.100g^{-1} (Table 1) as a result of degradation. In the production of malt, the degradation process known as modification, causes structural changes in the barley endosperm cell walls, starch granules and their surrounding protein matrix are partially hydrolysed by enzymes **(Nielsen *et al.*, 2017)**. **Gianinetti (2009**) observed the degradation of β-glucan in barley grain during the malting process by using fluorescent staining. Author found out that the amount of β-glucan in the grain after 3 days of malting, decreased by a half. After 4 days of malting, the grain contained about 3/4 of β-glucans from its original content.

Table 1 Degradation of β-glucan in barley grain and malted barley during malting process

Variety	Barley		Steeping		Germination					
					1. day		2. day		3. day	
	enz. (g.100g^{-1})	FIA (g.100g^{-1})	enz. (g.100g^{-1})	FIA (g.100g^{-1})	enz. (g.100g^{-1})	FIA (g.100g^{-1})	enz. (g.100g^{-1})	FIA (g.100g^{-1})	enz. (g.100g^{-1})	FIA (g.100g^{-1})
Malz	3.91	3.25	1.87	1.95	0.91	1.24	0.38	0.33	0.25	0.13
Kangoo	3.77	4.16	1.64	1.83	0.69	0.90	0.36	0.32	0.18	0.11
Overture	3.92	4.67	2.31	2.30	0.67	1.40	0.34	0.32	0.20	0.16
Laudis 550	3.08	2.37	1.79	2.10	0.89	0.97	0.35	0.34	0.18	0.11
Karmel	4.63	3.62	1.95	2.83	1.25	1.62	0.43	0.38	0.20	0.18
Valis	4.24	2.95	1.97	2.45	1.05	1.21	0.41	0.31	0.22	0.19
Exalis	3.70	2.98	1.80	2.28	0.69	1.01	0.32	0.23	0.15	0.11
Kumran	3.88	3.30	2.22	3.10	1.11	1.16	0.52	0.40	0.16	0.09

Legend: The values represent the means of three replicate determinations (maximum relative standard deviation ± 5%), enz.- enzymatic method, FIA-flow injection analyses method

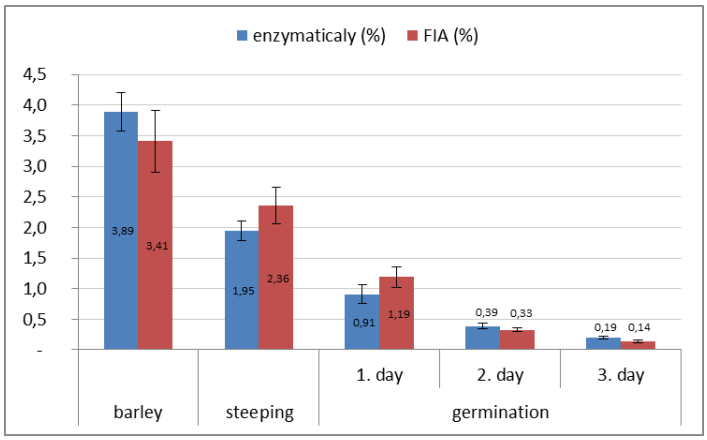

Figure 1 Average values of β-glucans with confidence levels in barley grain and malted barley during malting process

In laboratory conditions, worts from evaluated malts were prepared, in which the content of β-glucan and also other important technological parameters (Table 2) were determined. The main goal of malting process optimization with respect to β-glucan content is to obtain the lowest possible concentrations in wort and, consequently, in beer. The lowest content of β-glucan in wort (enzymatic method) was measured regarding Kangoo variety 49 mg.dm^{-3} and the highest values reached the Karmel variety 127 mg.dm^{-3} (Figure 2). However, in everyday practice, higher values are tolerated (**EBC, 2010)**. The European Brewery Convention **EBC (2007)** tolerates a limit of <250 mg.dm^{-3}. According to several authors **Marconi *et al.* (2014); Basařová *et al.* (2015**) the optimal content of β-glucan in wort is considered to be amount of 150 and 250 mg.dm^{-3}. Our results showed that evaluated worts reached values lower than 150 mg.dm^{-3} (Figure 2). This lower content of β-glucan indicates good cytolytic modification and such malt will not cause problems with wort filtration in the brewery. The content of β-glucan in malt may to some extent affect the content of β-glucan in wort, as can be seen in Fig. 2, where the variety with a low content of β-glucan in the malt also expressed the lowest content of β-glucan in the wort. In conclusion, despite the different values in the β-glucan content, the lowest content was found in the variety Kangoo and the highest in the variety Karmel (Figure 2), using both methods. It can be seen that process of malting exhibited the very good degradation results with respect to the initial concentration of β-glucan in the grain. Due to the malting process the average content of β-glucan decreased by 97 % from barley to wort.

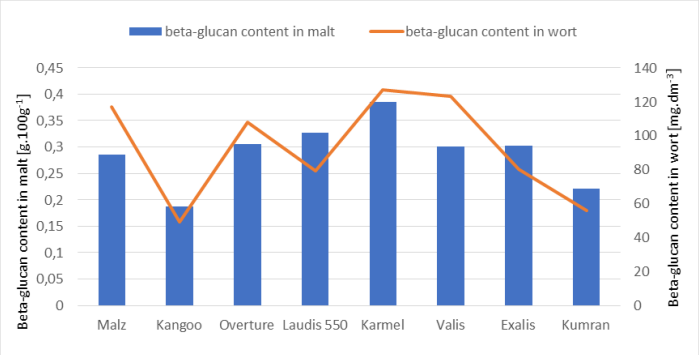

Figure 2 β-glucan content in malt and wort by enzymatic method

Results were compared by one-way repeated measures analysis of variance (ANOVA), (Table 4). According to obtained results it can be stated that there is statistically nonsignificant difference between the results measured by the enzymatic method and the FIA method. Therefore, for the determination of the β-glucan content in barley, malted grain, malt and wort, both methods are applicable without major differences, taking into account measurement errors. **Psota *et al.* (2015**) used the FIA method to analyse β-glucan in barely varieties trials. The FIA method demands laboratory equipment, but provides the ability to analyse a large number of samples. The basic advantages of enzymatic analysis include its low demand on laboratory equipment, but the method requires the use of specific enzymes and chemicals.

Regarding other technological malt parameters (Table 2), the lowest moisture content in malt was measured in the Malz variety (6.25 %) and the highest 6.6 % in the Exalis variety. Although, malts had a moisture content of 4 % right after kilning process, the moisture content increased slightly during the storage. Malt is very strongly hygroscopic material and it must be stored at the optimum temperature and humidity. The average value of friability in evaluated malts was 85.9 %. The lowest measured value of friability was 80 % (variety Exalis) and the highest 93 % reached varieties Malz and Kangoo. **Dolan (2003)** states if values of friability are between 80 and 90 %, malt is considered to be of good quality. **Nielsen and Munck (2003)** found out that friability values depend on barley variety. Authors found out friability from 84 to 93 % regarding the first variety and 76 to 87 % in the second monitored variety. Based on the obtained results, it can be stated that all evaluated malts showed optimal cytolytic modification. On the other hand, malts with a friability value of more than 90 % are considered to be overmodified. The malt extract values reached 82.9 % in average. The Malz variety reached the highest extract 83.9 %, while the lowest extract 82.2 % was measured in the Laudis variety. Values higher than 80 % are considered to be the optimal malt extract values. If the malt is perfectly modified, the values of the extract are higher. Extract is the most important parameter of the malt quality (**Eßlinger and Narziß, 2009; Kunze, 2014; Lowe *et al.*, 2005).** According to **Li *et al.* (2008**) it determines the amount of beer that can be produced. The main effort is to achieve a high extract in terms of quality and quantity of beer. Evaluated malt extracts reached higher values more than 80 %, with the low content of β-glucan, therefore we can assume uniform grain modification. The colour of malt wort reached 7.71 EBC units in average. The lowest colour value was measured in wort from the Kumran variety (5.31 EBC units) and the highest in the Malz variety (10.42 EBC units). According to **Steiner *et al.* (2011)** required values for the wort colour range from 7 to 11 EBC units. The colour of the wort is the result of products formed by the Maillard reaction from free amino nitrogen and reducing sugars. Only three evaluated wort met the required values for wort colour. Moreover, the wort turbidity was measured at angle of 13° and 90°. The average turbidity value at angle of 13° was 1.24 EBC units and 1.01 EBC units at 90°. The lowest turbidity was measured in the Malz variety and the highest in the Valis variety. **Psota *et al.* (2015)** measured turbidity at angle of 90° in wort from the Malz variety (0.63 EBC units) and our achieved values were comparable (0.68 EBC). Turbidity values are shown in Table 2. The average viscosity value for the 8.6 % extract was 1.44 mPa.s^{-1}. The lowest viscosity of 1.42 mPa.s^{-1} was measured in the Malz variety and the highest 1.46 mPa.s^{-1} in the Overture and Valis varieties (Table 2). The European Brewery Convention **EBC, (2010) and EBC (2007)** tolerate an average viscosity for 8.6 % extract 1.47 mPa.s^{-1}. Viscosity value <1.53 mPa.s^{-1} represents a very good level of degradation.

Table 2 Malt and wort technological parameters

Malt Varieties	Malt moisture (%)	Malt Friability (%)	Extract in d.m. (%)	Wort color (EBC)	Wort turbidity 13° (EBC)	Wort turbidity 90° (EBC)	Wort viscosity 8.6% (mPa.s^{-1})
Malz	6.25	93.0	83.90	10.42	0.60	0.68	1.42
Kangoo	6.30	93.0	82.45	9.71	0.84	0.92	1.43
Overture	6.35	91.0	82.49	9.58	1.00	0.98	1.46
Laudis 550	6.38	86.0	82.22	6.82	1.64	1.09	1.44
Karmel	6.28	81.5	83.18	6.47	1.36	0.97	1.45
Valis	6.46	82.0	82.80	6.55	2.04	1.35	1.46
Exalis	6.60	80.0	83.15	6.82	1.51	1.09	1.44
Kumran	6.41	80.5	83.34	5.31	0.92	0.98	1.43

Legend: The values represent the means of three replicate determinations (maximum relative standard deviation ± 5%)

Table 3 Correlation matrix of analyzed parameters of barley, malt and wort

Parameter	Protein content in barley (%)	Starch content in barley (%)	BG in barley (g.100g^{-1})	BG in malt (g.100g^{-1})	BG in wort (mg.dm^{-3})	Friability (%)	Extract (%)	Wort color (EBC)	Wort turbidity 13° (EBC)	Wort turbidity 90° (EBC)
Starch content in barley (%)	**-0.9666**									
BG in barley (%)	-0.4337	0.4371								
BG in malt (%)	**0.8146**	**-0.7317**	0.2674							
BG in wort (mg.dm^{-3})	0.5302	-0.4829	0.2832	0.3398						
Friability (%)	**-0.9430**	**0.9690**	0.1452	-0.3794	-0.2378					
Extract (%)	-0.4738	0.4835	0.2793	0.1215	-0.1181	-0.0944				
Wort color (EBC)	**-0.7013**	**0.7806**	0.4801	0.3388	-0.0769	**0.7204**	0.2203			
Wort turbidity 13° (EBC)	0.2597	-0.1924	-0.1474	0.0323	0.1975	-0.5229	-0.1760	-0.5969		
Wort turbidity 90° (EBC)	0.0867	-0.0693	0.1145	0.0794	0.1182	-0.5086	-0.0054	-0.4776	**0.8597**	
Wort viscosity 8.6 % (mPa.s^{-1})	0.6655	-0.6181	0.4406	**0.8656**	0.0905	-0.1397	0.1569	0.5383	-0.0533	0.1415

Legend: The marked correlations are significant at level (P < 0.05); BG – β-glucans

When analysing the statistical correlations among the content of β-glucan in barley grain and in malt its significance value reached a coefficient of 0.2674 that represents a positive correlation with very low significance rate (Table 3). **Wang *et al.* (2004)** in their study also compared these two parameters and similarly did not confirm statistical differences among these parameters. Based on the obtained results, it can be stated that the β-glucan content in barley grain has no significant effect on the β-glucan content in malt. The β-glucan content could be affected by the malting process. According to **Mareček *et al.* (2017)** the content of β-glucan in barley grain is in a negative correlation with the starch content, but the results of our work pointed to a statistically insignificant degree of dependence (Table 3). Authors **Mareček *et al.* (2017**) found a negative highly significant correlation (r = -0.682) among malt friability and β-glucan content in wort. In our work such significance has not been confirmed. Table 3 shows positive correlation (r = 0.9690) among friability and the starch content of barley with a significance level ($p < 0.05$). Grains with higher starch content have a lower content of crude protein and non-starch polysaccharides. Non-starch polysaccharides negatively influence the grain modification process during malting and thus adversely affect malt friability. This statement is also related to the determined correlation among the content of nitrogen-substances in barley and malt friability. Our results confirmed a negative statistical significant ($p < 0.05$) correlation (r = -0.9430) among this parameters. **Mareček *et al.* (2017**) reported a positive correlation among starch content in barley and malt friability. We also confirmed from our results a negative

correlation between nitrogen-substances in barley and malt friability. A positive significant correlation among β-glucan content in malt and the viscosity of wort was found ($r = 0.8656$) with a level of significance ($p < 0.05$). This means, the high content of β-glucan in malt would increase the viscosity of the wort. **Nagamine *et al.* (2009)** also found out a positive correlation among these analysed parameters. The correlation among the content of β-glucan in wort and the viscosity was not statistically significant, the correlation coefficient was at the level $r = 0.0905$. According to scientific work of **Jin *et al.* (2004)** a positive correlation between these parameters with a significance level of ($p < 0.001$) was found.

Table 4 Determination of differences between enzymatic method and FIA method of β-glucan in barley grain and malted barley during malting process based on one-way repeated measures analysis of variance (ANOVA)

Source of Variation	SS	df	MS	F
Methods	0.005138	1	0.005138	0.00293
Error	164.8569	94	1.753797	
Total	164.862	95		

Legend: SS-Sum of Squares, df-degree of freedom, MS-Mean Square

CONCLUSION

Based on the obtained results it can be concluded that malting process positively affects the content of the β-glucan in final wort. In particular, the total β-glucan content decreases during the malting process. Already, the average value of the β-glucan content in the samples decreased from 3.89 g.100g^{-1} to the amount of 0.19 g.100g^{-1} determined enzymatically and from 3.41 g.100g^{-1} to 0.14 g.100g^{-1} measured by the flow injection analyses method. All evaluated samples fulfilled requirements for β-glucan content in wort, values were lower than 250 mg.dm^{-3}. From the achieved results we can state that due to malting process the average content of β-glucan from barley to wort decreased by 97 %. According to obtained results it can be stated that there is statistically nonsignificant difference between the results measured by the enzymatic method and the FIA method. Moreover, a positive significant correlation among the content of β-glucan in malt and the viscosity of worth was found ($r = 0.8656$) with a level of significance ($p < 0.05$) which means that the high content of β-glucan in malt would increase the viscosity of the wort. Significant correlation among the β-glucan content in wort and the viscosity was not proven. The content of β-glucan in wort is important for brewers, because its higher amount has a negative effect on beer production, mainly on brewing yield, flow rate and the wort viscosity. In the final beer, the formation of turbidity can negatively affect the sensory impression of the beer.

Acknowledgements: This work was supported by Drive4SIFood 313011V336.

REFERENCES

Basařová, G., Psota, V., Šavel, J., Basař, P., Paulů, R., Kosař, K., Dostálek, P., Basařová, P., Kellner, V., Mikulíková, R., Čejka, P. (2015). *Sladařství. Teorie a praxe výroby sladu*. 1st edition. Praha: Havlíček Brain Team. ISBN: 978-80-87109-47-2

Beer, M. U., Wood, P. J., Weisz, J. (1997). Molecular weight distribution and (1 → 3) (1 → 4)-β-d-glucan content of consecutive extracts of various oat and barley cultivars. *Cereal Chemistry*, 74 (4), 476-480. https://doi.org/10.1094/CCHEM.1997.74.4.476

Behall, K. M., Scholfield, D. J., Hallfrisch, J. (2004). Lipids significantly reduced by diets containing barley in moderately hyper-cholesterolemic men. *Journal of the American Nutrition Association*, 23, 55-62. https://dx.doi.org/10.1080/07315724.2004.10719343

Briggs, D. E. (1998). *Malts and Malting*. Selection and purchase of grains. Blackie Academic & Professional. London, ISBN:0412298007

Cimini, A., Moresi, M. (2014). Beer clarification using ceramic tubular membranes. *Food and Bioprocess Technology*, 7, 2694-2710. https://dx.doi.org/10.1007/s11947-014-1338-2

Cimini, A., Moresi, M. (2015). A novel cold sterilization and stabilization process applied to a pale lager. *Journal of Food Engineering*, 145, 1-9. https://dx.doi.org/10.1016/j.jfoodeng.2014.08.002

Cimini, A., De Francesco, G., Perretti, G. (2017). Effect of crossflow microfiltration on the clarification and stability of beer from 100% low-β-glucan barley or malt. *LWT-Food Science and Technology*, 86, 55-61. https://dx.doi.org/10.1016/j.lwt.2017.07.033

Dolan, C. S. T. (2003). Chapter 2 – Malt whiskies: raw materials and processing. *Whisky: Technology. Production and Marketing*. Academic press, p. 27-73. ISBN 978-0-12-669202-0. https://dx.doi.org/10.1016/B978-012669202-0.50019-1

Eßlinger, H. M., Narziß, L. (2009) Beer. *Ullmann's Encyclopedia of Industrial Chemistry*, (vol. 5), p.217-220. https://dx.doi.org/10.1002/14356007.a03_421.pub2

European Brewery Convention, 2007. The new malting barleys for Europe. In *Journal of the Institute of Brewing*, 113 (4), 1-27. https://dx.doi.org/10.1002/j.2050-0416.2007.tb00748.x

European Brewery Convention Analysis committee, 2010, Analytica EBC. Nüremberg: Fachverlag Hans Carl. ISBN 978-3-418-00759-5.

Gianinetti, A. 2009. A theoretical framework for β-glucan degradation during barley malting. *Theory in Biosciences*, 128 (2) 97-108. https://dx.doi:10.1007/s12064-008-0055-7

Goudar, G., Sharma, P., Janghub, S., Longvah, T. (2020). Effect of processing on barley β-glucan content, its molecular weight and extractability. *International Journal of Biological Macromolecules*, 162, 1204-1216. https://dx.doi.org/10.1016/j.ijbiomac.2020.06.208

Habschied, K., Lalić, A., Horvat, D., Mastanjević, K., Lukanic, J., Jukić, M., Krstanović, V. (2020). β-Glucan Degradation During Malting of Different Purpose Barley Varieties. *Fermentation*, 6, (1), 2020. https://dx.doi.org/10.3390/fermentation6010021

Holtekjølen, A. K., Uhlen. E., Bråthen. S., Sahlstrøm, S. H. (2006). Contents of starch and non-starch polysaccharides in barley varieties of different origin. *Food Chemistry*, 94, 348-358. https://dx.doi.org/10.1016/j.foodchem.2004.11.022

Izydorczyk, M. S., Dexter, J. E. (2008). Barley β-glucans and arabinoxylans: molecular structure, physicochemical properties, and uses in food products. *Food Research Inernational*, 41, 850-868. https://dx.doi.org/10.1016/j.foodres.2008.04.001

Jin, Y. L., Speers, A., Paulson, A., Stewart, R. (2004). Effects of β-Glucans and Environmental Factors on the Viscosities of wort and beer. *Journal of The Institute of Brewing*, 110 (2) 104-116. https://dx.doi.org/10.1002/j.2050-0416.2004.tb00189.x

Kunze, W. (2014). *Technology Brewing and Malting*, 5th Ed., Berlin, Germany, pp. 960. ISBN 978-3-921690-77-2.

Li, Y., Schwarz, P. B., Barr, J. M., Horsley, R. D. (2008). Factors predicting malt extract within a single barley cultivar. *Journal of Cereal Science*, 48 (2) 531-538. https://dx.doi.org/10.1016/j.jcs.2007.12.004

Lowe, D. P., Arendt, E. K., Soriano, A. M., Ulmer, H. M. (2005). The influence of lactic acid bacteria on the quality of malt. *Journal of The Institute of Brewing*, 111 (1) 42-50. https://dx.doi.org/10.1002/j.2050-0416.2005.tb00647.x

Marconi, O., Tomasia, I., Dionisio, L., Perretti, G., Fantozzi, P. (2014). Effects of malting on molecular weight distribution and content of water-extractable β-glucans in barley. *Food Research International*, 64, 677-682. https://dx.doi.org/10.1016/j.foodres.2014.07.035

Mareček, V., Mikyška, A., Hampel. D., Čejka. P., Neuwirthová. J., Malachová. A., Cerkal. R. (2017). ABTS and DPPH methods as a tool for studying antioxidant capacity of spring barley and malt. *Journal of Cereal Science*, 73, 40-45. https://dx.doi.org/10.1016/j.jcs.2016.11.004

Nagamine, T., Sekiwa, T., Yamaguchi, E., Oozeki, M., Kato, T. (2009). Relationship Between Quality Parameters and SKCS Hardness Index in Malting Barley. *Journal of the Institute of Brewing*, 115 (4) 292-295.https://dx.doi.org/10.1002/j.2050-0416.2009.tb00383.x

Newman, R. K., Newman, C. W. (2008). *Barley for Food and Human Nutrition: Science, Technology, and Products*, 1st Ed. Willey, New Jersey, 260 p. ISBN: 978-0-470-10249-7

Nielsen, J. P., Munck, L. (2003). Evaluation of malting barley quality using exploratory data analysis. I. Extraction of information from micro-malting data of spring and winter barley. *Journal of Cereal Science*, 38 (2) 173-180. https://dx.doi.org/10.1016/S0733-5210(03)00023-7

Nielsen, M. S., Damkjær, K. B., Feidenhans'l, R. (2017). Quantitative in-situ monitoring of germinating barley seeds using X-ray dark-field radiography. *Journal of Food Engineering*, 198, 98-104. https://dx.doi.org/10.1016/j.jfoodeng.2016.11.011

Psota, V., Sachambula, L., Svorad, M., Musilová, M. (2015). Odrůdy ječmene registrované ve Slovenské republice v roce 2015. *Kvasný průmysl*, 61 (5) 147-151. https://dx.doi.org/10.18832/kp2015017

Runavot, J-L., Bakan, B., Geneix, N., Saulnier, L., Moco, K., Guillon, F., Corbineau, F., Boivin, P. Marion, D. (2011). Impact of low hydration of barley grain on β-Glucan degradation and lipid transfer protein (LTP1) modifications during the malting process. *Journal Agricultural Food Chemistry*, 59, (15), 2011, 8256–8264. https://dx.doi.org/10.1021/jf2011134

Sharma, P., Gujral, H. S. (2014). Anti-staling effects of β-glucan and barley flour in wheat flour chapatti. *Food Chemistry*, 145, 102-108. https://dx.doi.org/10.1016/j.foodchem.2013.08.021

Steiner, E., Auer, A., Becker, T., Gastl, M. (2011). Comparison of beer quality attributes between beers brewed with 100 % barley malt and 100 % barley raw material. *Journal of the Science of Food and Agriculture*, 92 (4) 803-813. https://dx.doi.org/10.1002/jsfa.4651

Wang, J., Zhang, G., Chen, J., Wu, F. (2004). The changes of β-glucan content and βglucanase activity in barley before and after malting and their relationships to malt qualities. *Food Chemistry*, 86, 223-228. https://dx.doi.org/10.1016/j.foodchem.2003.08.020

Woonton, B., Jacobsen, J. V., Sherkat, F., Stuart, I. M. (2005). Changes in germination and malting quality during storage of barley. *Journal of the Institute of Brewing*, 111 (1) 33–41. https://dx.doi.org/10.1002/j.2050-0416.2005.tb00646.x