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Comparison of Brewing Performance using 100% Unmalted Grains: Barley, Wheat, Oat and Rye

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Introduction

- Beer is traditionally made from malted barley (malt). With the development of brewing enzymes, it becomes realistic to brew beers using unmalted grains with the addition of mashing enzymes [1-3].
- The use of unmalted grains (**Fig. 1**) becomes an interesting topic due to several benefits:
  - ✓ Savings of EUR 0.5-1.0 per hectoliter of beer depending on local grain and enzyme price
  - ✓ Elimination of carbon footprint associated with malt production, reducing CO_2 emission by 8g per 33cl of beer [2]
  - ✓ Direct use of local crops, making the beer production more **sustainable**
- However, brewing with 100% unmalted grains in combination with added enzymes remains mostly unknown. Moreover, there is no brewing performance published for 100% unmalted wheat, oat, and rye as raw ingredients.

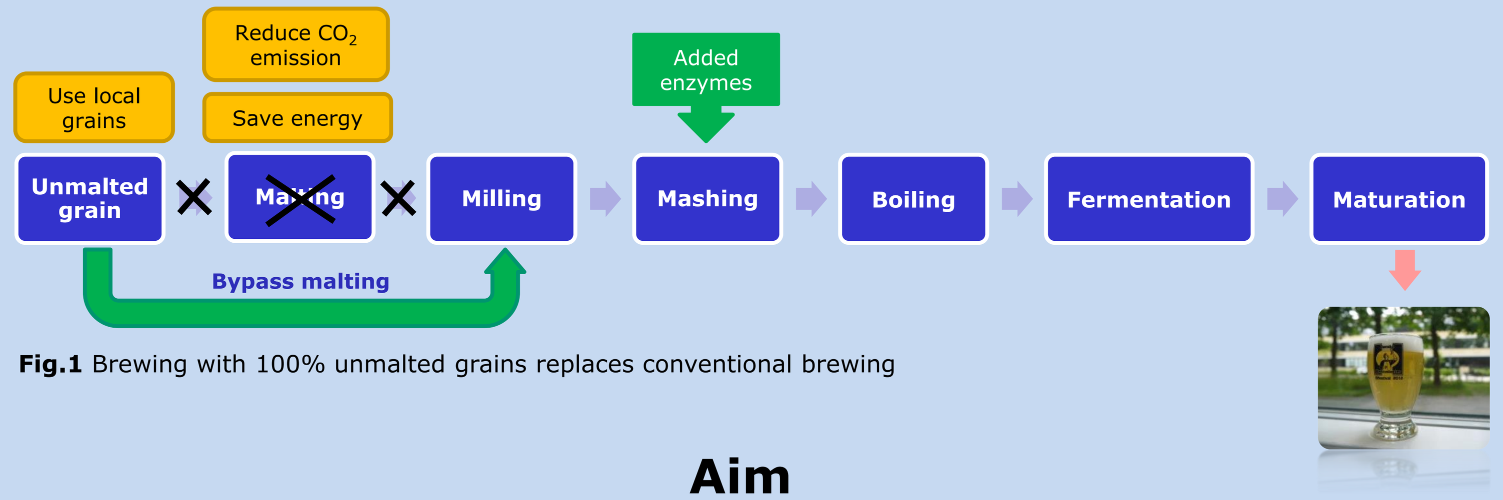

Fig.1 Brewing with 100% unmalted grains replaces conventional brewing

Aim

- To compare the quality attributes of worts and beers produced entirely from 100% unmalted barley, wheat, oat and rye by applying commercial **brewing enzymes**
- To examine the **specification** of brewing with 100% unmalted grains compared to a standard 100% malt brew
- To provide information for **process optimization** and **new product development**

Materials and Methods

- **Grains:** food-grade unmalted barley, wheat, rye and oat were purchased from Aurion A/S, Denmark, and malt (type 'pilsner') was from Maltfabrik A/S, Denmark.
- **Enzymes:** a brewing enzyme mix Ondea® Pro which includes a mixture of enzymes namely α-amylase, β-glucanase, xylanase, protease, pullulanase and lipase was kindly provided by Novozymes A/S, Denmark.
- **Brewing:** an identical brewing method (**Fig. 2**) was adopted at 10L-scale for each grain type.
- **Analytical methods:** specific gravity, total nitrogen, viscosity, haze, free amino nitrogen (FAN) and colour of worts or beers were determined using a density meter (Mettler-Toledo Instruments, Denmark), the Kjeldahl method, a rheometer (Reologica Instruments AB, Sweden), a spectrophotometric method (OD560), EBC 8.10 and EBC 9.6, respectively. Carbohydrate compositions of worts, as well as ethanol and glycerol contents of beers were determined by HPLC. Volatile flavour compounds of beer samples were determined using headspace GC-MS.

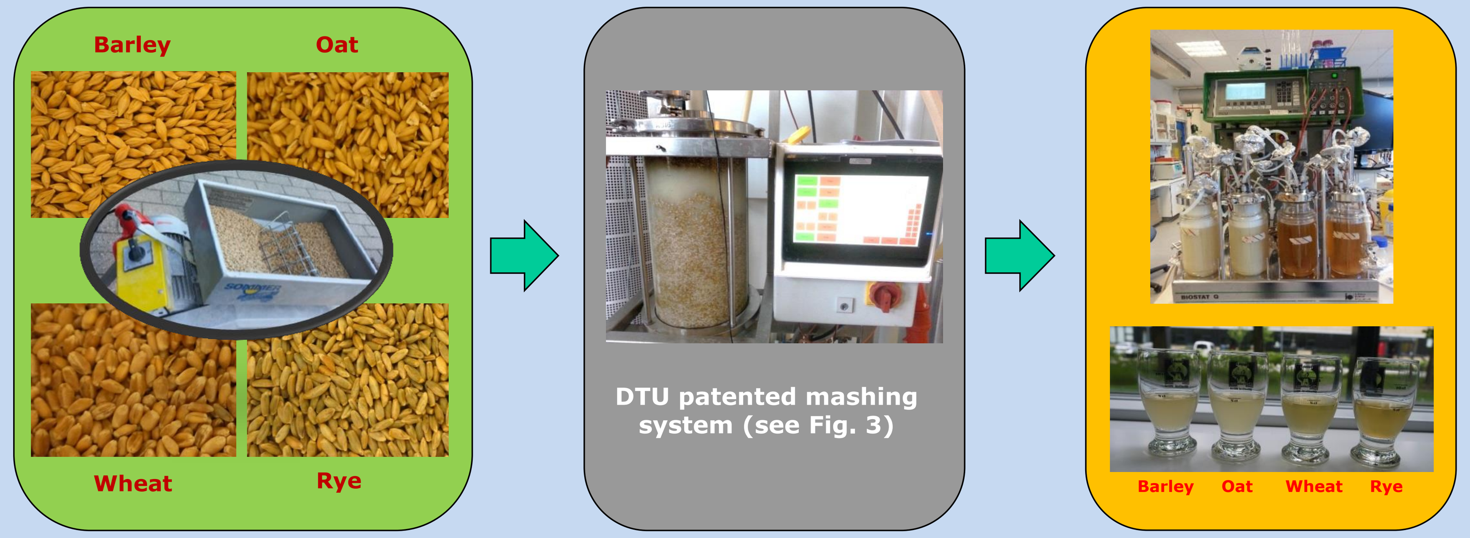

Fig. 2 Brewing process used for each grain type with addition of a commercial mashing enzyme (Ondea® Pro)

Characterization of worts

- Mashing system: mashing was carried out in a mashing system constructed in house (**Fig. 3**). The system allows good mixing of the wort, mash cake and enzymes, which was observed (glass mash tun) to ensure a uniform mashing process for all 100% unmalted grain types.
- Extract: in order to provide a reasonable comparison, sparge water was added to reach an extract of ca. 11°P before boil and all the worts showed an extract of ca. 12°P after boil (**Table 1**).
- Sugars: various compositions of carbohydrates were observed in the worts (**Fig. 4**). For the most abundant wort sugar maltose, oat wort contained the lowest concentration of 24.7g/L compared to the highest value of 68.5g/L in malt wort.
- FAN: worts produced from unmalted grains contained lower FAN compared to malt wort. It is advisable to perform an additional protein rest or to supplement with additional enzymes in order to improve FAN contents for brewing with 100% unmalted grains.
- Viscosity: rye wort showed the highest viscosity value, whereas worts made from oat, barley and wheat had much lower viscosity, which is closer to that of malt wort.

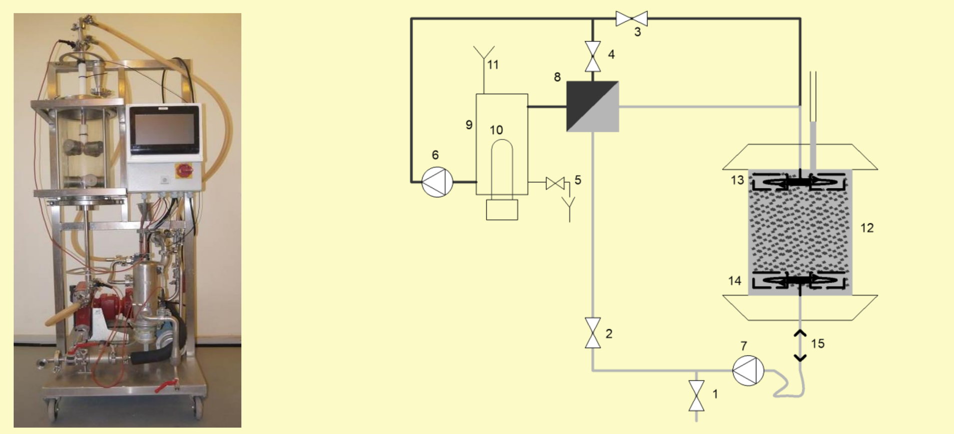

Fig.3 Image and diagram of the mashing system used in this study. The system contains a 13 L mash tun, a heat exchanger and a touchscreen control system

Table 1 Characteristics of worts. Data is presented as the mean of the duplicate samples ± range of the duplicates

		Wort types				
	unit	Barley	Wheat	Oat	Rye	Malt
Specific gravity	°P	11.5 ± 0.1	11.8 ± 0.2	12.4 ± 0.1	12.3 ± 0.1	11.7 ± 0.1
Total nitrogen	%, w/w	0.09 ± 0.01	0.19 ± 0.03	0.12 ± 0.01	0.09 ± 0.02	0.10 ± 0.01
FAN	mg/L	63.2 ± 0.7	90.9 ± 3.4	78.9 ± 1.4	85.2 ± 2.0	154.1 ± 4.7
Viscosity	mPa×s	1.64 ± 0.03	1.79 ± 0.01	2.11 ± 0.04	5.15 ± 0.03	1.52 ± 0.03

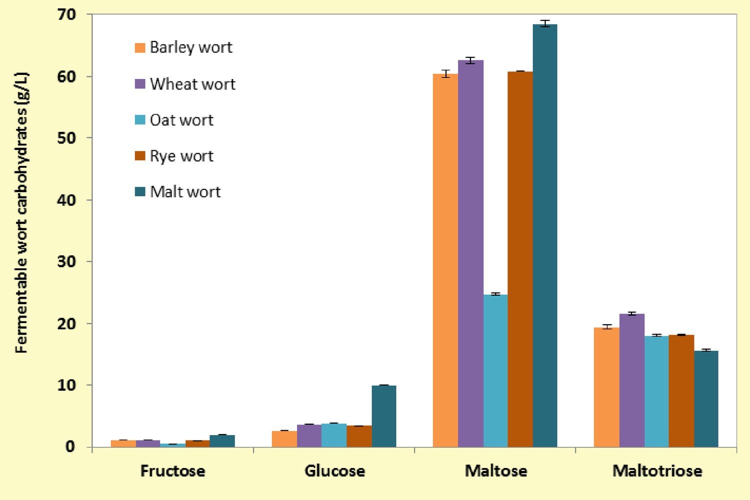

Fig. 4 Concentrations of fermentable carbohydrates in different types of wort

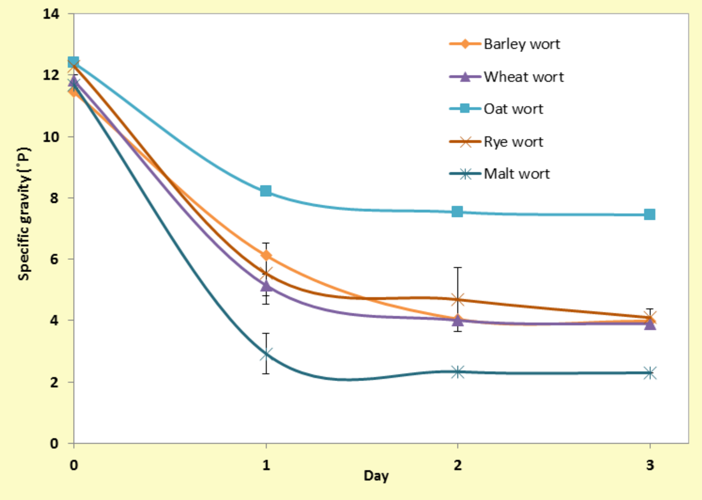

Fig. 5 Decrease in specific gravity during fermentations, which were carried out using a dry ale yeast at 20°C with stirring

Characterization of beers

- Alcohol: oat fermentation resulted in the lowest ethanol content, along with the highest residual gravity (**Table 2**), likely due to higher un-fermentable extract in oats (higher protein, lipid, etc).
- FAN: the value was higher in malt beer than beers produced from unmalted grains. Irrespectively, a similar degree of FAN utilisation (approx. 80%) was observed, indicating that amino acid profiles of the worts were equally beneficial for the yeast, regardless of the grains used.
- Colour: beers made from unmalted grains had a lighter colour compared to malt beer according to EBC method. In particular, oat was the lightest, whereas rye beer was the closest to malt beer.
- Brightness: wheat and malt beers were the brightest, whereas rye beer was the most cloudy pint, indicating rye beer contains relatively higher levels of proteins and polyphenols.
- Flavour: beers produced from unmalted grains show different flavour profiles (**Table 3**), although the concentrations are generally lower than malt beer.

Table 2 Characteristics of beers. Data is presented as the mean of the duplicate samples ± range of the duplicates.

		Beer types				
	unit	Barley	Wheat	Oat	Rye	Malt
Residual gravity	°P	4.0 ± 0.1	3.9 ± 0.1	7.5 ± 0.1	4.1 ± 0.3	2.3 ± 0.1
Degree of fermentation	%	65.2 ± 0.3	67.0 ± 0.9	40.0 ± 0.7	66.7 ± 1.0	80.3 ± 0.1
Ethanol	%, v/v	3.42 ± 0.13	3.93 ± 0.03	2.22 ± 0.01	3.87 ± 0.07	4.61 ± 0.13
Glycerol	g/L	2.58 ± 0.15	3.60 ± 0.89	1.70 ± 0.29	3.27 ± 0.17	3.83 ± 0.27
FAN	mg/L	11.6 ± 1.2	21.7 ± 4.2	18.7 ± 3.0	17.2 ± 5.1	36.7 ± 0.5
Degree of FAN utilisation	%	81.6 ± 2.1	76.3 ± 3.8	76.4 ± 3.5	79.8 ± 5.5	76.1 ± 1.1
Colour	EBC unit	3.7 ± 0.1	4.9 ± 0.2	3.1 ± 0.3	6.5 ± 0.3	7.6 ± 0.1
Haze	OD560	0.21 ± 0.02	0.13 ± 0.04	0.29 ± 0.05	0.78 ± 0.02	0.08 ± 0.01

Table 3 Summary of higher alcohols and esters (mg/L, data is presented as the mean of the duplicate samples ± range of the duplicates)

			Beer types				
Flavours	Flavour description	Normal range [a]	barley	oat	wheat	rye	Malt
Higher alcohols							
n-propanol	solvent-like	4-17	10.2 ± 0.3	9.9 ± 0.6	14.5 ± 0.3	10.9 ± 1.2	27.0 ± 1.9
Isobutanol	alcoholic, malty,	4-60	28.0 ± 0.2	16.2 ± 0.6	22.1 ± 0.7	24.2 ± 1.3	40.0 ± 6.0
Σ 2- and 3-methyl-1-Butanol	fruity, sweet	5.6-140	29.0 ± 0.2	13.5 ± 0.5	26.0 ± 0.4	28.1 ± 2.1	35.0 ± 4.1
Esters							
Ethyl acetate	fruity	5-50	5.5 ± 0.4	3.1 ± 0.2	5.3 ± 0.3	4.7 ± 0.5	23.0 ± 4.0
Ethyl propionate	Sweet, grape	0,01-10	0.056 ± 0.009	0.024 ± 0.002	0.048 ± 0.001	0.034 ± 0.004	0.130 ± 0.009
Isoamyl Acetate	banana, apple	0.3-8	0.120 ± 0.003	0.049 ± 0.003	0.270 ± 0.022	0.121 ± 0.015	3.500 ± 0.56
Isobutyl acetate	banana, sweet, fruity	0.01-0.8	0.009 ± 0.001	0.004 ± 0.001	0.016 ± 0.001	0.007 ± 0.002	0.210 ± 0.045
Ethyl butyrate	papaya, sweet fruity	0.004-0.4	0.043 ± 0.001	0.004 ± 0.001	0.045 ± 0.005	0.030 ± 0.006	0.109 ± 0.009

[a] Values were obtained from flavour database of American Society of Brewing Chemists.

Future works and collaboration

- Sensory: it would be interesting to investigate the consumer's feedback towards such beers that used 100% unmalted grains in future study.
- Mashing optimization: it should be noted that an identical mashing method was used for all grains in the current study and future work should investigate optimizing wort production using enzyme supplementation or modified mashing profile for specific grain type.
- BSG: apart from these, the authors are also interested in recovery of valuable products from brewer's spent grain (BSG). Currently, the liquid and solid fraction of BSG could be separated efficiently by a compact filter (DTU-patented) constructed in house (**Fig. 6**).
- Collaborations: DTU Brewery is a non-profit brewery that can brew beer from lab scale to pilot plant level up to 200L (**Fig. 7**). We are open to new ideas and collaborations.

Fig. 6 The compact filter used for dewatering of brewer's spent grain

Fig. 7 DTU brewery has a capacity of upto 200L

References and Acknowledgements

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SUMMARY

- This study provides valuable information for exploring beer brewing with 100% unmalted oat, rye or wheat using exogenously added enzymes.
  - ✓ In particular, beer produced from 100% unmalted oat was found in simple tasting by the authors to have a much different flavour profile in comparison to beers made from 100% rye, wheat, barley or malt.
  - ✓ However, oat wort has lower concentrations of maltose than others, resulting in a low alcohol concentration.
- In general, worts produced from unmalted grains have lower concentrations of FAN as well as higher viscosity compared to malt based wort.
  - ✓ Additionally, there is a decrease in the levels of colour, brightness, higher alcohols and esters in beers produced from unmalted grains than in the beer produced from malt.
- It is concluded that supplementation with additional FAN or exogenous enzymes is essential to optimise brewing with 100% unmalted grains.
  - ✓ Further experimental studies are needed to examine sensory quality parameters, and to evaluate the technological feasibility at commercial scale, especially for 100% unmalted oat beer.