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Effect of mashing procedures on brewing

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Abstract The effect of the double decoction mashing method (method A) and the single decoction plus infusion mashing method (method B) on brewing were compared. The trials were carried out with the same raw material (malt and a minor amount of corn as adjunct) on an industrial-scale plant. The effects of mashing methods A and B were evaluated in wort and beer samples obtained with the high gravity system. The analytical parameters of the worts and beers produced and the economic aspects of production (yield, beer quality, time and energy) were discussed. The results showed no considerable differences in beer quality, while a significant difference was observed in the composition of fermentable sugars of worts. Method B gave a wort with a higher content of fermentable sugars which were converted to alcohol during fermentation; therefore, it allowed to obtain a higher beer volumetric yield of the same quality while saving time and energy.

Keywords Mashing · Decoction · Infusion · Wort · Beer · Brewery yield

Introduction

Mashing is an important step in the brewing process and it influences the type and quality of the produced beer. The aim of mashing is to produce a wort containing suitable amounts of fermentable sugars, yeast nutrients and flavour compounds. The final wort composition depends on the temperature–time profile adopted which changes according to the type and quality of the finished beer. The goal when choosing a suitable temperature–time profile is to produce a wort with the desired properties [1]. Resting the mash at a specific temperature is important for inducing certain enzymatic changes.

Mashing involves:

1. dissolving substances which are directly soluble in water;
2. enzymic hydrolysis followed by dissolving a series of substances important for the type and character of beer;
3. separation of the dissolved substances.

During brewing, the result of the enzymatic action is to break down large macromolecules from malt into smaller molecules necessary for yeast growth and fermentation. In fact, starch is broken down into fermentable sugars that are readily transformed into alcohol content by yeast. The enzymes involved in the hydrolysis of substances include amylases, proteases, peptidases, transglucosidases and phosphorylases. The main factors that regulate the activities of these enzymes are temperature, pH, time and concentration of the wort [2]. The thermostability of starch-hydrolyzing enzymes is critical for the fermentable sugar yield during mashing. In fact, the mashing temperature profile is a balance between the temperature required for starch gelatinization needed to enable efficient hydrolysis and the rate of thermal inactivation of these enzymes [3]. Two major starch-digesting enzymes are released from malt, α- and β-amylase. Temperatures of 60–65 °C maximize the activity of β-amylase whilst 65–70 °C are necessary to allow α-amylase to operate [4, 5].

Alpha-amylase very rapidly reduces insoluble and soluble starch by splitting its molecules into many shorter chains (i.e., partially fermentable polysaccharide fractions, dextrin and maltotriose) that can be attacked by β-amylase. Given a long enough "rest", α-amylase can

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dismantle all the dextrins to maltose, glucose, and small, branched "limit dextrins." However, starch conversion by the faster-acting β-amylase is more effective. Beta-amylase is more selective than α-amylase since it breaks off two sugars at a time from the starch chain. Beta-amylase begins to sequentially remove units of maltose from the non-reducing end of large dextrins. It produces maltose, the most common sugar in malt. Overall, α- and β-amylases are capable of converting only 60–80% of the available starch into fermentable sugars. Proteases comprise the group of enzymes that reduce high-molecular-weight proteins to simpler amino acid constituents by breaking the peptide bonds between proteins. Proteinase and peptidase are the two main enzymes belonging to this group. The "protein rest" is responsible for reducing the overall length of high-molecular-weight proteins in the mash—which cause foam instability and haze—to low-molecular-weight proteins [5, 6].

The mashing methods can be divided into two main categories: infusion mashing and decoction mashing. Infusion is most commonly associated to the production of ales and stouts, but is also successfully used by some lager brewers. The decoction method, developed largely as a result of the use of under-modified or enzymatically weak malts, is generally used in the production of lager beers. In this system a portion of the mash (the decoction) is removed for boiling and then returned into the main mash to increase the temperature. Decoction mashing involves one-, two- or three-decoction steps, and gives origin to single-, double- or triple-decoction mashes [6].

In this work the effect of the double decoction mashing method (method A), and the single decoction plus infusion mashing method (method B), on brewing are compared. Generally, methods A and B are applied to different raw material compositions in order to obtain the best yield and qualitative results.

The effect of methods A and B on wort composition and beer quality is evaluated from a chemical and an economic point of view. The samples of worts and the relative beers are analyzed by determining the pH, the carbohydrates, the polyphenols and the total soluble nitrogen.

Materials and methods

Wort and beer production

The industrial scale mashing experiments were carried out in an Italian beer factory. This factory is one of the most recent and modern in Italy. All operations are achieved with modern technologies and are overseen 24 h a day by technicians through the control room. Full yearly production capacity is approximately 1,000,000 hl. The beer was produced with the high gravity system using the mashing methods A and B. The total volume of the mash tun used was 400 hl.

Wort sampling was performed after wort cooling and before yeast pitching, while beer sampling was performed after bottle packaging. Sodium azide (NaN_3, 10 mg/l) was added to wort samples to stop microbial growth. Three industrial trials using methods A and B were carried out producing worts with 17 Plato degree (°P) and beers with 5% v/v of alcoholic content.

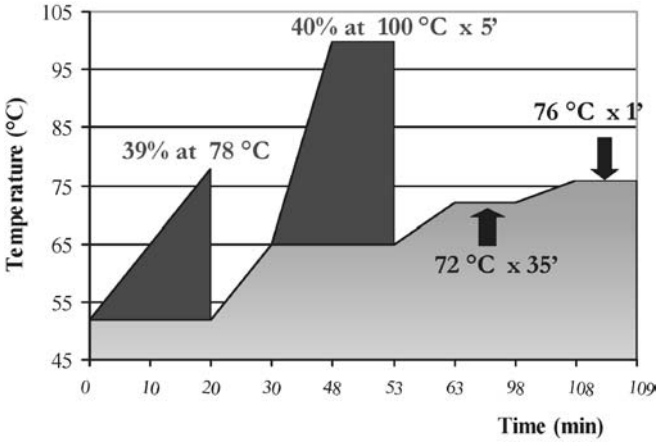

Fig. 1 Temperature vs time in the double decoction method

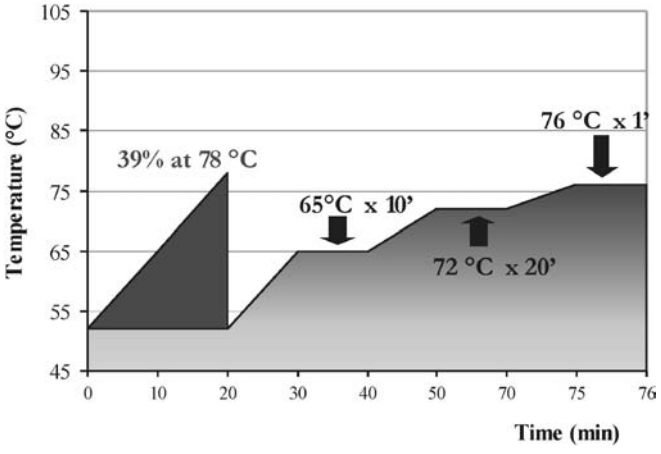

Fig. 2 Temperature vs time in the single decoction plus infusion method

Mashing method A

Briefly, the grist was mashed with hot water at 52 °C. The first decoction was performed by removing 39% of the mash to a separate vessel which was heated to 78 °C and returned to the main mash to obtain a temperature of 65°C. A second decoction was performed removing 40% of the mash which reached the boiling temperature in 18 min, and was maintained at this temperature for 5 min and when returned to the main mash the temperature increased from 65 °C to 72 °C in 10 min. The mash was maintained at 72 °C for 35 min. Afterwards the temperature was raised to 76 °C in 10 min. The mash was maintained at 76 °C only for 1 min (Fig. 1).

Mashing method B

The time regimes for the first stage of decoction mashing were the same used for method A. Following this, temperature-time regimes adopted on total mass were 65, 72 and 76 °C with holding times of 10, 20 and 1 min respectively (Fig. 2).

Wort and beer analyses

Three industrial trials were carried out and each analysis was performed in double, therefore the reported data are the mean of six values.

pH

The pH measurement was performed using a pH-meter. Wort pH was determined directly while the beers were degassed before analysis.

Total carbohydrates

Total carbohydrates content was determined according to Fehling method [7]. Fifty millilitres of diluted wort or beer samples were hydrolyzed with 5 M HCl for 30 min at 80 °C to convert oligosaccharides to glucose, and then the Fehling's reagent was titrated with the hydrolyzed sample to determine the total carbohydrates content.

Fermentable carbohydrates profiles

All the fermentable oligomeric carbohydrates (fructose, glucose, sucrose, maltose, maltotriose) were quantitatively evaluated.

Good reproducibility and sensitivity for all carbohydrates were obtained in 40 min, using amino-bonded silica column, aqueous/acetonitrile gradient elution profile at room temperature, an Evaporative Light Scattering Detector (ELSD), and an easy sample preparation [8].

Total and non tannic polyphenols

Total polyphenols (TP) content was determined according to the Singleton method [9]. Non tannic polyphenols (NTP) were determined according to the Montedoro and Fantozzi method [10] in degassed beer and diluted wort with water in a 1:2 ratio (v/v).

Total soluble nitrogen

The soluble nitrogen content of wort and beer was determined using the Kjeldahl method.

Results and discussion

The effect of two different mashing methods on wort and beer properties was compared. Mashing methods A and B were chosen after considering the composition of the raw materials and the quality of the final product. Generally, decoction processes are performed for irregularly or poorly modified malt but, if adjuncts containing starch with a high gelatinisation temperature are to be used, they should be precooked in a special vessel before being mixed in with the malt mash [11]. In this study the adjuncts were used directly without precooking. At the beginning the mash was at temperature of 52 °C which allowed the proteolytic enzymes to operate [12]. Then a portion of mash was held at 78 °C, inactivating the amylolytic enzymes, and remixed again with the main mash reaching 65 °C. The second decoction, with boiling, stopped the enzymatic activity. In method B, the first step is the same but the second decoction was substituted by a temperature-programmed infusion. In this phase the temperature of the stirred mash was progressively raised to 76 °C with rest at 65, 72 and 76 °C.

The effects of the two mashing procedures were evaluated on the worts and the respective beers by determining the pH, the polyphenols, the total soluble nitrogen and the total carbohydrates profile. Table 1 reports the pH value and total nitrogen concentration of samples A and B. The results confirmed literature data [13]. Wort pH values are characteristic of the recipe and are uniform from brew to brew within a beer brand. Significant variations from the norm affect fermentation, beer flavour and flavour stability [14].

Table 1 pH and total nitrogen concentration of wort and beer

Sample	pH	sd	Total nitrogen	
			mg/l	sd
Wort A	5.22[c]	0.10	1040[e]	200
Wort B	5.30[c]	0.10	1140[e]	80
Beer A	4.47[d]	0.10	510[f]	40
Beer B	4.46[d]	0.10	510[f]	50

Value in the same column followed by the same superscript are not statistically different ($P<0.05$) $n=6$
sd: standard deviation

Table 2 Total polyphenols (TP) and non tannic polyphenols (NTP) concentration in wort and beer sample

Sample	TP		NTP	
	mg/l	sd	mg/l	sd
Wort A	571.1[c]	26.0	482.3[e]	3.7
Wort B	578.7[c]	22.7	483.3[e]	4.6
Beer A	272.1[d]	13.6	262.2[f]	14.6
Beer B	277.2[d]	13.2	266.3[f]	7.0

Value in the same column followed by the same superscript are not statistically different ($P<0.05$) $n=6$
sd: standard deviation

The amount of nitrogen in wort is important during fermentation, and it influences beer flavour properties. Wort nitrogen comprises protein content and the free amino nitrogen which is fundamental for yeast nutrition [15]. The nitrogenous compounds found in beer vary widely in their chemical configuration and so does their influence on beer odour, flavour, character and biological development. The amino compounds found in beer are almost exclusively nitrogenous compounds that are not utilized by yeast. The volatile nitrogen-containing constituents of beer are particularly important because many of them are present at levels significantly above their very low flavour thresholds [16].

Table 2 shows the TP and NTP concentration. The phenolic compounds present in beer seem to be able to contribute to the total antioxidant capacity of plasma (TRAP) and probably of other body compartments, thus reinforcing the defences against oxidative stress [17]. They contribute to astringency and colour, serve as browning substrates, participate in chill haze formation and are responsible for overall beer stability [18].

The pH, total nitrogen and TP and NTP data were compared using Student's paired t test. The statistical results confirm that no significant differences ($P<0.05$) were found between wort and beer samples produced with the two mashing methods proposed.

Table 3 Total and fermentable carbohydrates concentration (HPLC method) and total carbohydrates concentration (Fehling method)

Sample	Fermentable carbohydrates (HPLC method)		Total carbohydrates (HPLC method)		Total carbohydrates (Fehling method)	
	g/l	sd	g/l	sd	g/l	sd
Wort A	152.1[c]	0.3	168.2[e]	7.9	162.7[c]	7.1
Wort B	157.4[d]	0.5	175.3[f]	6.3	166.1[f]	4.8
Beer A	4.8[g]	0.4	23.0[h]	3.0	29.4[i]	1.4
Beer B	4.7[g]	1.7	22.6[h]	4.7	29.6[i]	1.5

Value in the same column and in the same row followed by the same superscript are not statistically different ($P<0.05$) $n=6$
sd: standard deviation

Table 4 fermentable carbohydrates profile (HPLC method)

Sample	Fructose		Glucose		Sucrose		Sucrose		Maltotriose	
	g/l	sd	g/l	sd	g/l	sd	g/l	sd	g/l	sd
Wort A	1.8[c]	0.3	15.4[d]	0.1	4.3[e]	0.9	105.4[f]	0.2	25.1[h]	0.7
Wort B	2.0[c]	0.2	16.1[d]	0.2	4.2[e]	0.6	108.4[g]	0.4	26.6[i]	0.2

Value in the same column followed by the same superscript are not statistically different ($P<0.05$) $n=6$
sd: standard deviation

Table 3 shows the total carbohydrates concentration of the wort and beer samples determined with HPLC and the Fehling method. The total amount of beer carbohydrates evaluated using the Fehling method are slightly higher than those evaluated with the HPLC method. This is probably due to the presence of fermentation products that also reduce reducing Fehling's reagent [8]. While no significant differences can be observed in the total sugars concentration in beers, nonetheless, it is interesting to note that wort B has a higher total sugars content than wort A. Wort B shows a greater concentration of fermentable sugars that are converted to alcohol during fermentation. Table 4 reports the fermentable carbohydrates profile of wort A and B. Statistical differences were only observed for maltose and maltotriose concentration ($P<0.05$). The different carbohydrates concentration between worts A and B confirms the diverse starch/fermentable sugar conversion of methods A and B. In method A, the second decoction was performed by removing 40% of the mash which reached the boiling temperature in 18 min inactivating a lot of enzymes (α- and β-amylases) thus obtaining a lower fermentable and total sugar yield. The different starch conversion does not influence the final beers, since they are produced using the high gravity system so the higher alcohol content obtained is able to increase beer volumetric yield.

In modern brewery the yield is about 100 hl of beer from 74 hl of wort. Each mash tun has a 400 hl capacity and the beer produced has a 5% v/v alcohol content. The higher fermentable sugars content (+5.3 g/l) corresponds to a 0.25% v/v alcohol increase (conversion factor of 0.5%). This work explains that from a single processed mash tun, either 540 hl of beer A with 5% v/v alcohol content or 540 hl of beer B with 5.25% v/v alcohol content can be obtained. Since the produced beer must have a 5% v/v alcohol content, starting from 540 hl of beer B with a 5.25% v/v alcohol content, 567 hl of beer with 5% v/v alcohol content can be obtained through dilution with a gain of 27 hl compared to method A.

From an economic point of view method B is cheaper than method A. It is due to the large amount of energy required in method A for boiling the second decoction, and maintaining the main mash at 65 °C. In method B, the hot treatment is applied to the total mash but it is carried out gradually. Furthermore, method B has a total process time of 76 min while method A is concluded in 109 min. The energy cost of method B is 20% lower than method A.

Conclusion

This study confirms that a single decoction plus infusion mashing method (method B) is more advantageous than a double decoction mashing method (method A). Both methods give wort and consequently beer with the same chemical characteristics, except for the starch/fermentable sugar conversion. In fact, method B is more convenient compared to method A, giving a higher fermentable sugars content (+5.3 g/l) corresponding to a 0.25% v/v alcohol increase. Infact, method B permits the best results producing a greater beer volumetric yield with time (33 min) and energy saving (20%).

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