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WHEN ALCOHOL LEAVES,

BREWING SHOWS.

WHITEPAPER 1 OF 2

WHITEPAPER

BarthHaas®

WHEN ALCOHOL LEAVES, FLAVOR SHOWS.

UNDERSTANDING HOW TO OPTIMIZE FLAVOR IN NON-ALCOHOLIC AND LOW-ALCOHOL BEERS

WHITEPAPER

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PART 1

UNDERSTANDING NON-ALCOHOLIC BEER PRODUCTION

NON-ALCOHOLIC AND LOW-ALCOHOL BEERS ARE HERE TO STAY …

In recent years, non-alcoholic beer has developed from a niche category to a significant segment in the international beverage market. The increasing demand results from growing health awareness, a trend towards moderate consumption and the desire for high-quality, taste-convincing alternatives to conventional beer. Today, modern production processes produce products that often come close to classic beers in terms of sensory aspects and at the same time offer nutritional advantages. Non-alcoholic and low-alcohol beers (NAB and LAB) are produced using biological and/or physical processes. In biological processes, ethanol formation is limited by using yeast strains with limited fermentation capacity or by stopping fermentation early. Alternatively, alcohol can be removed from the beer by physical methods such as thermal processes, extraction or membrane-based processes. This first white paper will focus on biological processes, while part 2 will shed light on physical methods.

UNDERSTANDING NON AND LOW-ALCOHOL BEER PRODUCTION OPTIONS AND WHAT THAT MIGHT MEAN FOR FLAVOR

WHY DOES NON-ALCOHOLIC BEER TASTE DIFFERENT?

If we like a beer, it is due to the optimal interaction of volatile and non-volatile flavors. These are esters, higher alcohols, aldehydes, ketones, sulfur flavors, terpenes and terpenoids on the volatile side. These act more via nasal/retronasal perception. Sugars, dextrins, amino acids, peptides, organic acids, polyphenols and minerals are non-volatile and act primarily via gustatory perception. In addition, there are trigeminal sensations of texture and temperature. All of this is supported by the flavor carrier ethanol.

Non-alcoholic beers generally contain the same chemical substance classes as beers containing alcohol. The sensory differences are therefore not primarily due to the absence of individual aroma components, but to altered concentrations, ratios and matrix effects. The non-existent (or only in very low concentrations) ethanol content affects the solubility, release, perception and integration of aroma and flavors.

Aldehydes that are formed during wort preparation are usually reduced to the corresponding alcohols by the yeast during fermentation. When using the stopped fermentation method, the corresponding non-alcoholic beers contain higher concentrations of aldehyde. Sensorially, this manifests itself in worty and sweet aromas, which can be very dominant in worty and sweet aromas and are perceived as rather unpleasant. When thermal dealcoholization is used, the thermal load in the finished beer can have an effect on grain-like or bread-like aromas. There is the possibility of restoring some of the lost aromas to the finished beer by recovering the aroma. It is also possible to add the mother beer used for dealcoholization to the finished beer up to the permitted alcohol concentration. Both are sensorially beneficial.

Esters are central carriers of many different fruity aromas. In interaction with terpene alcohols and thiols, they determine the intensity of the fruitiness of the beer aroma. Hops provide a variety of volatile flavoring compounds, including monoterpene alcohols such as linalool and geraniol, sesquiterpenes as well as thiol compounds. The use of intense hop flavors is often part of the solution to compensate for sensory gaps.

Iso-αAcids, humulinones and polyphenols are present in quantities comparable to those found in alcoholic beer. Sensorially, however, the bitterness is often perceived as stronger and more persistent. This is due less to the absolute amount of bitter acids than to the lack of ethanol, which has a positive effect on the interactions between sweetness and bitterness and supports the mouthfeel.

In addition to the volatile and non-volatile flavors, carbon dioxide (CO_2) and ethanol are indispensable for a full-bodied taste experience. CO_2 has a significant impact on all distinguishable sensory properties, including the suppression of sweetness and the alteration of bitterness. CO_2 interacts with bitter substances and enhances the aftertaste. Ethanol is the main factor in the sensation of warmth and complexity in the mouth. The solubility and volatility of the flavorings are directly influenced by the ethanol content. Ethanol also enhances the perception of sweetness and enters into complex interactions with bitter substances and CO_2.

In the range of 0.5-3.0%, these sensorially positive aspects of ethanol are already very clear, which is a strong advantage for low-alcohol or light beers. Any small amount of ethanol that is allowed by law offers a sensory advantage. Even though there are great efforts to offer 0.0% beers to consumers, you have to keep in mind that many supposedly alcohol-free drinks such as juices or spritzers can contain up to 0.5% alcohol and, depending on consumer behavior, this alcohol content increases after opening.

YOUR KEY TAKEAWAYS:

Non-alcoholic beer tastes different not because flavor components are missing, but because removing ethanol disrupts how flavors are balanced, released, and integrated.

In practice:
- You may expect more worty/aldehyde notes (stopped fermentation) or cooked/grainy notes (thermal dealcoholization)
- Aroma may express as weaker and less integrated, even if compounds are present
- Bitterness can be harsher and lingers longer
- Overall beer may feel thinner, less complex, and less balanced

What to consider:
- Reduce aldehydes through process and yeast selection
- Rebuild aroma (e.g. dry hopping, flavor additions)
- Adjust bitterness and mouthfeel to restore balance
- Where possible, allow small amounts of ethanol (≤ 0.5%) to improve flavor integration

How are production methods linked to flavor impact?

The sensory characteristics of non-alcoholic beers are closely linked to the production process. When fermentation is stopped, high aldehyde contents remain, while esters and higher alcohols are formed only to a limited extent. Many brewers then choose maltose-negative yeasts that enable a more targeted formation of fermentative flavorings with a low ethanol content at the same time. In membrane and osmotic processes, the flavoring substances behave according to their size and polarity and are depleted accordingly. Fig. 1 shows very clearly the difference in percentages for different flavoring substance groups compared to a mother beer (MB) for a lager and a wheat beer that was produced as a non-alcoholic beer using different processes.

percentage deviation from the MB (scale: 100.0 to -100.0)

	Wheat beer MB	Wheat beer LF	Wheat beer SY	Wheat beer TH	Wheat beer RO	Lager MB	Lager LF	Lager SY	Lager TH	Lager RO
ketones	0.0	-100.0	-97.4	-100.0	-100.0	0.0	-100,0	-98.3	-100.0	-100.0
terpene alcohols	0.0	-85.1	-68.9	-99.0	59.3	0.0	-46.0	-26.8	-98.4	76.5
terpenes	0.0	-94.5	-94.4	-97.6	-27.4	0.0	-79.7	-93.3	-99.8	-30.9
lactones	0.0	-76.0	-13.3	-60.6	46.9	0.0	-70.2	-28.7	-67.0	24.3
aromatic hydrocarbons	0.0	-91.4	-40.9	-44.2	16.7	0.0	-70.2	631.4	-32.3	52.7
methyl esters	0.0	-94.1	-62.7	-99.1	32.6	0.0	-56.4	-77.1	-99.7	44.3
acetate esters	0.0	-97.7	-8.6	-99.4	-23.9	0.0	-97.2	-51.0	-99.9	-19.0
ethyl esters	0.0	-97.5	-0.3	-99.2	-24.2	0.0	-96.9	-48.6	-99.8	-20.3
primary alcohols	0.0	-93.7	0.0	-86.4	19.9	0.0	-95.0	-47.5	-99.0	12.4
sulfuric compounds	0.0	-70.1	-70.8	-99.2	-97.3	0.0	30.5	9.4	-98.9	-90.6

Figure 1: Percentage difference in the concentration of flavoring groups compared to mother beer (MB), wheat beer and lager, measured by HS-SPME GC-MS. (LF= limited fermentation; SY = special yeast; TH= thermal dealcoholized, RO= reverse osmosis) (Söhnke 2026)

The biological production processes used when producing non-alcoholic and low-alcohol beers

The various processes for the production of non-alcoholic beers can be divided into biological and physical processes. This white paper focuses on the use of specialty yeasts, but will provide a brief overview of all biological processes. Biological processes are often based on a modified mashing process in combination with a modified fermentation process. In part two, we will focus on the physical production processes and how to optimize flavor when using them.

Table 4: Overview of biological processes

BIOLOGICAL PROCESSES	
Modified mashing process	**Modified fermentation methods**
High-temperature mashing (75-80 °C) / jump mashing process	Cold contact (1 °C)
Cold extraction / cold mashing process (<60 °C)	Stopped/arrested fermentation
Re-mashing of the spent grains / last runnings	Continuous fermentation
	Special yeasts

In addition to the focus on fermentation and how it can be influenced, the mashing process is crucial. While for regular brewing we try to make as much extract as possible available to the yeast as fermentable sugar, in the biological processes we try to do more or less the opposite, because where there is no sugar, no alcohol can be produced. It is important to know the enzymes that are important for the mashing process and their function in detail in order to respond to the changed requirements for a mashing process that is suitable for the production of alcohol-free beers.

Table 5 shows all temperature ranges for the enzymes that are important in the mashing process. >>

Table 5: Temperature ranges for the enzymes important in the mashing process. (Bohak, 2005)

CYTOLYSIS				
Enzyme	**Temperature optimum in mash [°C]**	**pH optimum in mash**	**Substrate**	**Product**
β-glucan solubilase	62–65	6.8	matrix-bound β-glucan	soluble high-molecular-weight β-glucan
Endo-1,3-β-glucanase	< 60	4.6	soluble high-molecular-weight β-glucan	low-molecular-weight β-glucan, cellobiose, laminaribiose
Endo-1,4-β-glucanase	40–45	4.5–4.8	soluble high-molecular-weight β-glucan	low-molecular-weight β-glucan, cellobiose, laminaribiose
Exo-β-glucanase	< 40	4.5	cellobiose, laminaribiose	glucose

PROTEOLYSIS				
Enzyme	**Temperature optimum in mash [°C]**	**pH optimum in mash**	**Substrate**	**Product**
Endopeptidase	45–50	3.9–5.5	proteins	peptides, free amino acids
Carboxypeptidase	50	4.8–5.6	proteins, peptides	free amino acids
Aminopeptidase	45	7.0–7.2	proteins, peptides	free amino acids
Dipeptidase	45	8.8	dipeptides	free amino acids

AMYLOLYSIS				
Enzyme	**Temperature optimum in mash [°C]**	**pH optimum in mash**	**Substrate**	**Product**
α-amylase	65–75	5.6–5.8	high- and low-molecular-weight α-glucans	malto-oligosaccharides
β-amylase	60–65	5.4–5.6	α-glucans	maltose
Maltase	35–40	6.0	maltose	glucose
Limit dextriase	55–60	5.1	limit dextrins	dextrins

OTHER IMPORTANT ENZYMES				
Enzyme	**Temperature optimum in mash [°C]**	**pH optimum in mash**	**Substrate**	**Product**
Lipase	55–65	6.8–7.0	lipids, lipid hydroperoxides	glycerol, free long-chain fatty acids, fatty acid hydroperoxides
Lipoxygenase (LOX)	45–55	6.5–7.0	free long-chain fatty acids	fatty acid hydroperoxides
Polyphenoloxidase	60–65	6.5–7.0	polyphenols	oxidized polyphenols
Peroxidase	< 60	6.2	organic and inorganic substrates	free radicals
Phosphatases	50–53	5.0	organically bound phosphate	inorganic phosphate

Various mashing processes have become established for the production of non-alcoholic beers.

1. HIGH-TEMPERATURE MASHING

To limit the fermentability, a mashing temperature above 75 °C can be used, as the β-amylase denatures and becomes inactive from about 70 °C. Since beta-amylase is primarily responsible for the release of maltose during mashing, the maltose content is reduced by the high-temperature mashing process. The saccharification of the starch is largely caused by alpha-amylase. This leads to the release of less fermentable sugars, but more non-fermentable sugars.

You can go up with temperatures up to 82 °C, but the higher the temperature, the greater the risk of extracting unpleasant tasting compounds from the malt. It must also be noted that the non-enzymatic starch hydrolysis increases with increasing temperature in the mash, so temperatures above 82 °C are not recommended.

2. JUMP MASHING

This process can be used when malt with insufficiently degraded protein is used. First, a thick mash with a water-to-grist ratio of 2:1 is mashed at 50 °C with a rest of 20–30 minutes. According to our own experience and regardless of the degree of protein solution, this rest can also be shorter (5–15 min). Boiling water is then added to increase the water-to-grist ratio to 4.3:1 and the temperature to about 75 °C. The mash is kept at this temperature for about an hour before it is further heated and mashed. Since β-amylase is inactivated, the fermentable extract of a wort produced with spring mash is low but should contain sufficient free amino nitrogen (FAN). The jump mashing process is very suitable for fuller-bodied beers, and the low amount of simple sugars means that the risk of over-fermentation is low. However, this procedure requires good process control. Compared to isothermal methods, it means more effort, as several vessels have to be used.

3. COLD MASHING

A mashing process with temperature below 50 °C and a 60 min mashing process will lead to approx. 4 °P gravity wort. This is low enough for the production of beers below 1% alcohol. A real cold mashing process is not very common but is possible. Cold mashing, also known as non-enzymatic mashing (NEM), means that the mash is left at 8 °C temperatures for 8–24 hours.

During cold mashing, an extraction of color, flavor and other compounds takes place. The starch conversion is minimal at these temperatures. Some fermentable sugars are produced, but at the same time you get a seasoning that is relatively rich in proteins. Since low temperatures are used here, microbiological hazards must be prevented by very hygienic work. Another option for limiting fermentability is to collect wort when gravity drops below a specific level. With this, the concentration of extract in the wort drops, pH rises and the level of undesirable material increases. Microbiological and sensory problems are also to be expected when using smooth water or spent grains for non-alcoholic beers, which is why these are not explained further here.

YOUR KEY TAKEAWAYS:

Biological NAB production is about controlling sugar availability with less fermentable sugar equating to less alcohol.

In practice:

- Mashing becomes critical: you deliberately limit fermentable sugars rather than maximise them.
- High-temp or jump mashing can deliver more body and will lead to low amount of alcohol
- Cold mashing can deliver more flavor extraction but higher microbiological risk
- Your fermentation approach (e.g. stopped fermentation, special yeasts) then builds on this foundation

What to consider:

- Optimize your mash profile first as this largely defines your alcohol ceiling.
- Balance low fermentability with enough FAN for yeast performance.
- Be cautious of flavor extraction and hygiene risks, especially at extremes.

Understanding the effects of altered fermentation

While production through continuous fermentation requires investment in special equipment, a modified mash regime, stopped or limited fermentation, as well as the use of special yeasts can be carried out in any brewery. The yeast Saccharomycodes ludwigii, which does not belong to the genus Saccharomyces, has been used commercially for this purpose for many years and is very popular.

Opting to use a different yeast is the easiest method for breweries, as it does not require investment in additional brewing equipment, making it accessible to breweries of all sizes.

However, the number of possible strains is infinite. Some of these strains can lead to higher pH values, meaning acidification is advisable. The yeasts that could be suitable for the production of non-alcoholic beers did not metabolize maltose or maltotriose, but showed sufficient tolerance to iso-α acids.

Possible strains that have been tested include the following:

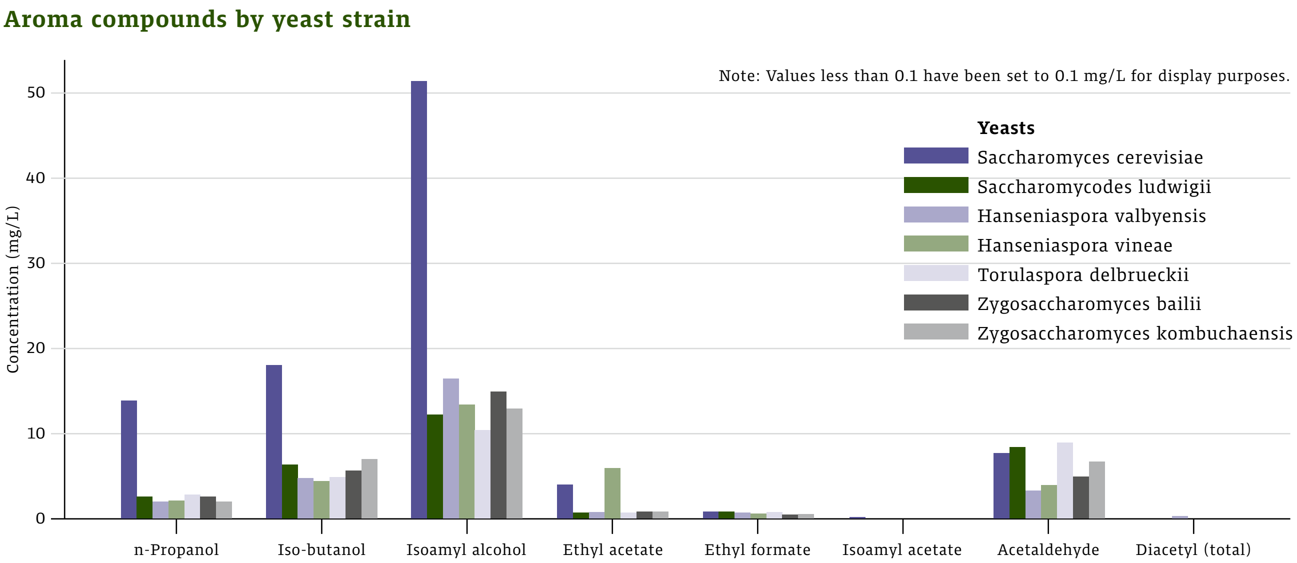
- **Candida shehatae,**
- **Candida zemplinina,**
- **Cyberlindnera mrakii (before Williopsis saturnus var. mrakii),**
- **Cyberlindnera fabianii,**
- **Torulaspora delbrueckii,**
- **Hanseniaspora valbyensis,**
- **Hanseniaspora vineae,**
- **Mrakia gelida,**
- **Pichia kluyveri,**
- **Pichia kudriavzevii,**
- **Zygosaccharomyces bailii,**
- **Zygosaccharomyces kombuchaensis**
- **Zygosaccharomyces rouxii**

Table 6: Important parameters for different non-Saccharomyces yeasts from different studies (Bellut & Arendt 2019)

Yeast type	Original gravity (°P)	Ethanol content (% v/v)	Time [d] / Temperature [°C] / Pitch rate [×10^6 cells/mL]	Secondary metabolites – esters (mg/L)	Sensory results
Candida shehatae	9	0.47	NA / 14 / NA	NA	NA
Candida zemlina	12	1.5	8 / 18 / NA	NA	NA
Cyberlindnera fabianii	12	0.6	7/20/NA	40:60 ratio	NA
Cyberlindnera mrakii	13.8	1.7	14 / 21 / 0.1	NA	NA
Hanseniaspora valbyensis	6.6	0.35	2 / 25 / 8	0.90 / 23.30	Worty, honey-like, grainy, diacetyl
Hanseniaspora vineae	6.6	0.34	2 / 25 / 8	6.00 / 20.2	Fruity, honey-like, black tea-like, caramel
Metschnikowia pulcherrima	12	1.16	22 / 10 / 0.4	6.7 / 5.25	Fruity (apricot, grape, lychee), malty
Pichia kluyveri	8.3	0.7	21 / 21 / 5	2.9 / 1.8	NA
Pichia kluyveri	8.3	0.1	21 / 20 / 5	2.5 / 2.0	Preference over commercially unfermented NAB
Pichia kudriavzevii	12	0.5	NA / 20 / NA	50:50 ratio	NA
Torulaspora delbrueckii	12.7	2.66	NA / 19 / 5	38.0 / 58.54	Fruity, citrusy, full-bodied
Torulaspora delbrueckii	12.5	2.62	NA / 19 / 5	4.56 / 61.99	Worty, honey-like, sweet
Torulaspora delbrueckii	6.6	0.5	3 / 25 / 8	0.77 / 18.1	Short maturation, honey-like
Torulaspora delbrueckii	12	0.83	NA / 27 / 15	2.23 / 5.60 / 203.36	Honey-like, fruity
Torulaspora delbrueckii	12.2	2.34	9 / 20 / NA	NA	Ester fruity, high body
Zygosaccharomyces bailii	6.6	0.42	4 / 25 / 8	1.00 / 23.1	Worty, honey-like, grassy, fruity, white grape
Zygosaccharomyces kombuchaensis	6.6	0.48	4 / 25 / 8	1.00 / 22.0	Worty, honey-like, diacetyl
Zygosaccharomyces rouxii	12	0.93	10 / 20 / NA	N.A. / 71.15 / 61.80–196.77	NA
Zygosaccharomyces rouxii	6	3.3	7/12/NA	NA	not comparable
Zygosaccharomyces rouxii	6	0.4	4 / 12.24 / 10	NA	low acceptance
Zygosaccharomyces rouxii	6	0.02	4 / 4.12.24 / 10.40	NA	low acceptance

The following figure shows how much the production of different aroma substances can vary depending on the strain (Britton, 2025)

Figure 2: Volatile compounds found in non-Saccharomyces yeast fermentation in non-alcoholic and low-alcohol beer



YOUR KEY TAKEAWAYS:

Changing yeast and fermentation is the easiest way to shape flavor in NAB without requiring new brewing equipment.

In practice:

- Non-Saccharomyces yeasts produce more interesting aromas but little alcohol (no maltose use)
- Different strains give very different flavor profiles
- Some can cause issues like higher pH or off-flavors, so control is needed

What to consider:

- Yeast choice is a key flavor lever. You may need to trial multiple strains to find your solution.
- You will likely need to monitor pH and adjust if needed.
- You can select strains based on your desired flavor profile, not just alcohol control.

PART 2

FLAVOR OPTIMIZATION IN NA-BEER PRODUCTION USING MALTOSE-NEGATIVE YEASTS

HISTORICAL BACKGROUND AND PECULIARITIES IN METABOLISM

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DEPUTY DIRECTOR OF THE RESEARCH CENTER WEIHENSTEPHAN FOR BREWING AND FOOD QUALITY

As Head of the Microbiology & Yeast Center Department at the TUM Research Center Weihenstephan for Brewing and Food Quality, he pioneered modern targeted yeast hunting in 2016. In 2021, he completed his habilitation in Beverage Microbiology and Technology at TU Berlin, followed by his appointment as Privatdozent at TU Munich in 2023.

An essential characteristic of maltose-negative yeasts is their limited carbohydrate metabolism. Conventional brewing strains of *Saccharomyces cerevisiae* (ale) and *Saccharomyces pastorianus* (lager) have developed a high degree of specialization in the uptake and fermentation of maltose and maltotriose – the dominant sugars in beer wort – through intensive domestication in brewery environments.

From an evolutionary point of view, the inability to metabolize maltose is by no means unusual. In natural habitats such as tree bark, fruits and flowers, maltose is rarely found compared to simple sugars. As a result, many wild yeasts have developed metabolic pathways that are mainly focused on glucose, fructose and sucrose.

In the wort of beer, these simple sugars typically account for only 10–15% of the total carbohydrates. This metabolic restriction represents a targeted technological advantage: maltose-negative yeasts ferment only this small fraction, resulting in natural carbonic acid and fermentation-typical aromas, while ethanol formation is naturally limited because they cannot utilize the remaining 85% of the extract.

Maltose-negative yeasts are an important lever for improving the sensory quality of non-alcoholic beers. Their importance is not limited to limiting ethanol formation, but lies primarily in their ability to produce positive aromas during fermentation while reducing undesirable wort notes. Maltose-negative yeasts can effectively reduce aldehydes and at the same time produce esters, higher alcohols and support aromas derived from hops. As a result, non-alcoholic beers taste closer to traditionally fermented beers.

Maltose-negative yeasts show clear differences in their individual aroma profiles. The interaction with hop-related flavoring substances such as terpenes, thiols and hop-specific esters can vary greatly. **Here is a summary of our own brewing attempts so far.**

Saccharomyces cerevisiae hybrid yeast strains often show a comparatively restrained and balanced aroma profile. The formation of monoterpene alcohols such as linalool, geraniol and citronellol occurs to a moderate extent, while thiols are formed only slightly. Ester formation also remains at a low to medium level. Sensory results in a clear, mildly fruity profile without pronounced aroma peaks. These characteristics make the strains particularly suitable for non-alcoholic beers with a traditional style, where freshness, balance and a lager-like character are required. Typical applications are non-alcoholic lagers, in which the yeast serves primarily as a neutral carrier of malt and hop character and not as a dominant aroma enhancer.

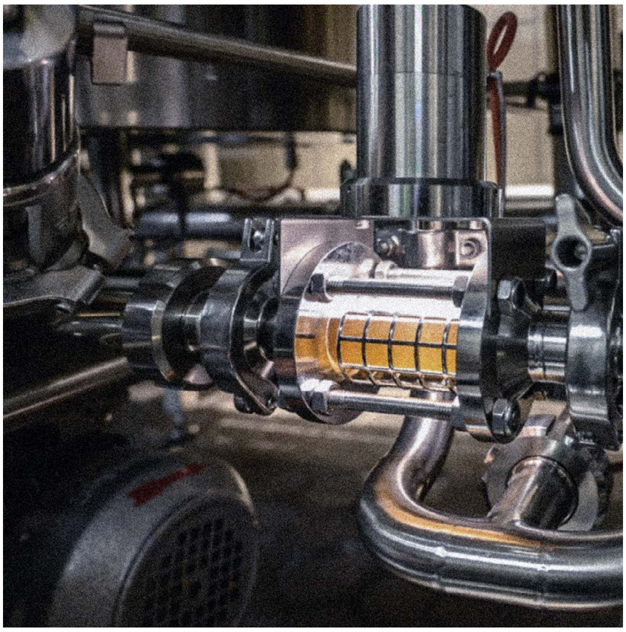
In contrast, *Saccharomyces cerevisiae var. chevalieri* shows a much stronger expression of fruity, hoppy aromas. This produces increased levels of monoterpenes such as myrcene and limonene as well as linalool derivatives, which provide a clearly pronounced citrus and floral aroma. Moderate thiol formation enables the formation of tropical-fruity aroma notes. This aroma profile makes *S. cerevisiae var. chevalieri* particularly suitable for hoppy, non-alcoholic beer styles such as pale ales and hop-intensive lagers.

The *Pichia kluyveri* strains show considerable variability in aroma expression within this yeast species. Depending on the specific strain, both the intensity and the relative contribution of thiols, terpenes and esters differ significantly. Individual strains are characterized by a pronounced formation of thiols, which give intense tropical fruit notes.

>>

Other strains of the same species have a broader and more balanced aroma profile, where the esters and terpenes derived from hops, along with thiols, contribute significantly to the overall impression.

This variability within the species *Pichia kluyveri* offers brewers a high degree of flexibility in product design. Strains with strong thiol formation are particularly suitable for non-alcoholic IPAs, NEIPAs and other modern, aroma-intensive beer styles where intensity and fruit character are paramount. Strains with a broader aroma profile create a more complex and rounded sensory impression with greater depth of aroma, making them suitable for non-alcoholic Hazy or Juicy beers as well as experimental craft formats. Strain-specific differences within *Pichia kluyveri* play a crucial role in the aromatic diversity of non-alcoholic beers and can be well used to compensate for the lack of ethanol.



How to do it:

From a technological point of view, the use of maltose-negative yeasts requires some adjustments in the brewing process compared to conventional brewer's yeasts. Since fermentation is limited to the small proportion of simple sugars in the wort, alcohol formation remains low even with moderate original worts. In order to achieve consistently stable products with these yeast strains, various process parameters must be taken into account:

Wort composition and original wort:

Relatively low original gravity (below 7 °P) is very suitable for keeping the minimum alcohol content in the alcohol-free range. Mash temperatures above 75 °C can also limit the formation of fermentable sugars and thus improve control over the final alcohol content (ABV = alcohol content by volume) and reduce residual sweetness. In addition, the addition of alternative raw materials (e.g. unmalted barley, oats, rye) in combination with adapted mashing processes offers further opportunities to control the proportion of fermentable sugars and the sensory perception of sweetness in a targeted manner.

Biological acidification:

The use of biological wort acidification (Sauergut) is strongly recommended in order to achieve a target pH value of below 4.5. This measure improves microbiological stability and ensures a fresh, balanced sensory profile. As a supplement, technical lactic acid can also be used to adjust the wort pH.

Fermentation and maturation:

Typical fermentations last about 3–4 days at temperatures between 15 °C and 25 °C. A subsequent ripening phase is essential to break down vicinal diketones (diacetyl). For most beer styles, post-carbonation (CO_2 adjustment) of the finished beer is essential before bottling. A thermal stabilization process (pasteurization) is required to ensure product safety, as any spoilage-causing (or brewing) yeast could subsequently ferment the remaining maltose in the bottle.

FLAVOR INSIGHTS:
SENSORY DIVERSITY AND BIOAROMATIZATION

The targeted selection of suitable yeast strains enables the production of specific aroma substances via targeted metabolic pathways. This significantly improves the sensor technology. In addition, certain strains have the enzymatic ability to specifically break down those aldehydes that are responsible for the aforementioned “worty” off-flavors. In this context, experiments with different strains at the Technical University of Munich (TUM-BLQ) have shown that beers fermented with these yeasts can have a diverse and vibrant SPECTRUM of fruity aroma profiles. This allows the lower ethanol content to be compensated for sensory, and brewers receive a flexible tool for product development.

Table 1: Maltose-negative yeast species for the production of non-alcoholic beers

TUM Strains	Species	Sensory profile
TUM SL17	*Saccharomycodes ludwigii*	Sweet, aromatic impressions, honey or caramel-like; excellent mouthfeel.
TUM 238	*Cyberlindnera misumaiensis*	Refreshing and balanced sweet and sour fruit aroma, reminiscent of gooseberry and stone fruit.
TUM 247	*Cyberlindnera saturnus*	High production of acetate esters; Banana, pear, berry and candy-like aromas.
TUM 653	*Cluyveromyces marxianus*	Balanced fruit profile with notes of apple, wild berries and honey.
TUM T1	*Torulaspora delbrueckii*	Pleasant, slightly fruity aromas with an overall neutral profile.
TUM 652	*Saccharomycopsis fibuligera*	Plum and strawberry-like aromas.
TUM 629	*Saccharomyces jurei*	Ester flavor and phenolic aromas. Can slowly break down maltose after a long delay. Temperature and original wort should be regulated for NoLo beer production.

”In practice, maltose-negative yeasts can be used in various ways. They can be used as purebred yeasts or in combination with other brewer’s yeasts in mixed fermentations to modulate the final aroma profile.

In addition, blending beers produced with different yeast strains can create complex and balanced sensory profiles and provide brewers with flexibility for product development. Working with mixed cultures in the production of non-alcoholic beers is also an option that creates balanced taste profiles.”

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SUMMARY OF ACTIONS YOU SHOULD TAKE TO LEVERAGE THE BENEFITS OF MALTOSE-NEGATIVE YEASTS:

- Use **maltose-negative yeasts** to limit alcohol while still generating fermentation-derived flavor
- Trial **multiple yeast strains** to match target beer style (neutral vs fruity vs tropical)
- Select yeast based on **desired aroma profil**e, not just alcohol control
- Adjust wort to **low gravity (<7 °P)** to control final ABV
- Use **high mash temperatures (>75 °C)** to reduce fermentable sugars
- Consider **alternative raw materials** (e.g. oats, rye, unmalted barley) to manage body and sweetness
- Apply **biological acidification (target pH <4.5)** to improve flavor balance and stability
- Run fermentations at **15–25 °C for ~3–4 days,** followed by **maturation to reduce diacetyl**
- Ensure **post-carbonation and pasteurization** to stabilize the final product
- Explore **mixed fermentations or blending** to build more complex flavor profiles
- Use yeast selection strategically to **reduce aldehydes and improve overall flavor quality**

KEY CHALLENGES

WHEN CREATING NAB/LAB BEERS USING MALTOSE-NEGATIVE YEASTS

HOW CAN HOPS AND HOP PRODUCTS BE USED TO OPTIMIZE FLAVOR IN BEER PRODUCED USING MALTOSE-NEGATIVE YEASTS?

What role do hops play in non-alcoholic beers? A major one, of course. The antimicrobial effect of hop bitter acids can be put to optimal use here. Hops provide the aromatic profile that these beers lack, and where ethanol cannot exert its effect, hops can help compensate. Each brewery selects the appropriate hop varieties based on the flavor and aroma desired for the finished beer. A certain level of bitterness is essential for the microbiological stability of non-alcoholic beer. During the hot wort stage, hops can be used as usual, either as pellets or as extract. The amount of hops does not need to be changed either. For intensely bitter beers, one might consider reducing the bitterness from boiling slightly, as the bitterness becomes more pronounced without alcohol. Here, the bitterness can be supplemented with hop products used during fermentation/lagering, bringing the Humulinones to the forefront, which impart a softer bitter taste.

A sensory key for alcohol-free beers is Dry-hopping. For a balanced dry-hop aroma, we recommend combining whirlpool hopping with dry hopping at the end of fermentation. We suggest splitting the amount of hops, with one-third in the whirlpool and two-thirds added at the end of fermentation.

Hop cones and hop pellets contain enzymatic power, known as “hop creep”, which can cause over-fermentation and thus an increase in alcohol content – something we definitely want to avoid in alcohol-free beers. Therefore, it is advisable to use liquid hop extracts, which contain no enzymatic potential but bring concentrated amounts of flavor and aroma compounds. For intensely hopped beers, SPECTRUM is best suited. SPECTRUM is available in many hop varieties and can be described as a liquid pellet. If a more moderate flavor impression is desired, PRYSMA® is recommended. Compared to SPECTRUM, PRYSMA® has the advantage that, due to its low viscosity, it can also be pumped into the beer stream using a dosing system. Both products offer everything crucial for alcohol-free beers: a concentrated amount of hop aroma compounds, including thiols, which are decisive for tropical flavor experiences. The residual amount of alpha acids in SPECTRUM is an additional advantage for microbiological safety. Both products deliver polyphenols, which positively influence mouthfeel. For both products, we recommend a replacement rate for pellets of approximately 1:8. This means that with 800 g of pellets per hectoliter for dry-hopping, 100 g of liquid extract per hectoliter would suffice. Of this, 35 g/hl can be added in the whirlpool and 65 g/hl at the end of fermentation or during maturation; in the case of PRYSMA®, it can also be dosed directly into the finished beer. Using these products has a number of advantages:

- Accurate, easy and fast dosing meaning you can adjust as you need to during the production process.
- Dosing options for all stages of production meaning that you can adapt as you need to, even post filtration.
- No hop creep meaning that you won’t need to worry about unintentional alcohol formation.

Below is a reference guide to some of the key challenges brewers face when creating NAB/LAB beers using maltose-negative yeasts, and how hops and hop products might be used to solve them.

YOUR KEY CHALLENGES WHEN CREATING NAB/LAB BEERS USING MALTOSE-NEGATIVE YEASTS

THE CHALLENGE:

THE FINAL BEER LACKS BODY

THE CAUSE:

Maltose-negative yeasts are unable to metabolize maltose and maltotriose, which together make up the majority of fermentable sugars in wort. As a result, only a small fraction of simple sugars (typically glucose, fructose, and sucrose) are fermented, leading to very low alcohol production but also lower generation of fermentation-derived compounds such as higher alcohols, esters, and other flavor-active metabolites. This restricted metabolism produces a beer that can taste worty, overly sweet, or underdeveloped, with reduced attenuation and a lack of the structural elements typically contributed by ethanol and fermentation by-products. The absence of these components diminishes mouthfeel, aromatic complexity, and overall balance.

POSSIBLE SOLUTIONS:

Use late kettle, dry hopping or post-fermentation/filtration hopping techniques to add in complex flavors, and add mouthfeel.

PRODUCT SOLUTIONS:

Lager-type NA beers	
LupoMAX®/LupoCORE™	We would recommend using pellets as a late kettle and/or dry-hop addition. This would be particularly good and building back flavor complexity and mouthfeel.
PRYSMA®/SPECTRUM	A good addition to the body are the use of liquid extracts. PRYSMA® might be preferred over SPECTRUM in this case as it does not impart additional bitterness and the flavor impact is less than with SPECTRUM.
PHA®	PHA® products can support the body without having a strong aroma impact. To increase body PHA® Sylvan, Floral and Spicy are recommended. Start with a dosing of of 10 g/hl.

Craft-type NA beers	
SPECTRUM	For a mouthfeel support start with 5 g/hl of SPECTRUM at end of fermentation. With higher additions the aroma impact will become more dominant.
PRYSMA®	For a mouthfeel support start with 7 g/hl of PRYSMA® at end of fermentation. With higher additions the aroma impact will become more dominant.
LupoMAX®/LupoCORE™	Dry Hopping will help to increase the body. If it is not about the flavor chose a variety with a lower oil content. Use about 100–150 g/hl for Dry-Hopping at the End of fermentation or in the lager tank. If you add more or other hop products at a later process point reduce accordingly.
PHA®	PHA® products can support the body without having a strong aroma impact. To increase body PHA® Sylvan, Floral and Spicy are recommended. Start with a dosing of of 10 g/hl.
HopHaze®	If you are looking for a hazy non-alcoholic beer this product will deliver a constant haze and additionally will add some mouthfeel. Start with a dosing of 50 g/hl.

THE CHALLENGE:

PRONOUNCED WORT AROMA AND/OR STRONG SWEETNESS IN NA BEER

THE CAUSE:

Working with a stopped fermentation results in rather high levels of Strecker aldehydes and higher alcohols, and can lead to high amounts of residual extract.

POSSIBLE SOLUTIONS:

Use of decoction mashing methods, lowering the original wort, use of specialty malts, adjusting bitterness units. Check the vitality of the yeast. Use of biological acidification Intensify boiling. Intense hop aroma in whirlpool (low whirlpool temperatures). CO_2 washing. Dry hopping to mask the wort aroma.

PRODUCT SOLUTIONS:

Lager-type NA beers	
PRYSMA®	For a good aroma to counteract with worty flavors start with 10 g/hl of PRYSMA®.
LupoMAX®/LupoCORE™	Depending on the hop variety and oil content of LupoMAX® aim for 2 ml of hop oil/hl (either all in the whirlpool or split 1/3 in the whirlpool and 2/3 for Dry Hopping). If you add more or other hop products at a later process point reduce accordingly.
PHA® Topnotes / PHA® Classics	With a chosen variety support your hop aroma with 10g of product/hl. As the impact is matrix dependent increase dosage until the aroma impact is as you need it.

Craft-type NA beers	
SPECTRUM	For a noticeable flavor start with 20 g/hl of SPECTRUM at end of fermentation. Aim for a total hop bill equivalent of about 500 g/hl (use a max. of 62,5 g/hl at a substitution rate of 1:8). If you add more or other hop products at a later process point reduce accordingly.
PRYSMA®	For a noticeable flavor start with 25 g/hl of PRYSMA® at end of fermentation. Aim for a total hop bill equivalent of about 500 g/hl (use a max. of 62,5 g/hl at a substitution rate of 1:8). If you add more or other hop products at a later process point reduce accordingly.
LupoMAX®/LupoCORE™	Depending on the hop variety and oil content of LupoMAX® aim for 4 ml of hop oil/hl (either all in the whirlpool or split 1/3 in the whirlpool and 2/3 for Dry Hopping). If you add more or other hop products at a later process point reduce accordingly.
PHA®	PHA® products can suppress unwanted flavors. We recommend to use PHA® Sylvan, Floral and Herbal for this application. Also PHA® Topnotes will help to cover unwanted aromas. Start with a dosing of of 10 g/hl.
HopHaze®	If you are looking for a hazy non-alcoholic beer this product will deliver a constant haze and additionally will add some mouthfeel and support aroma. Start with a dosing of 50 g/hl.

THE CHALLENGE:

UNPLEASANT BITTERNESS

THE CAUSE:

With ethanol and also residual extract missing the bitterness will show differently. This is a bigger issue with dealcoholization methods than biological processes.

POSSIBLE SOLUTIONS:

Residual extract and biological acidification will help the bitterness to integrate better.

PRODUCT SOLUTIONS:

Lager-type NA Beers	
LupoMAX®/LupoCORE™	We would recommend using a certain amount of pellets as a late kettle and/or dry-hop addition. The vegetative flavor in low amounts helps the bitterness to integrate with the overall flavor. Start with a dosing of of 50–75 g/hl.
PRYSMA®/SPECTRUM	A good addition to the body are the use of liquid extracts. PRYSMA® might be preferred over SPECTRUM in this case as it does not impart additional bitterness and the flavor impact is less than with SPECTRUM. Start with 7,5 g/hl of PRYSMA® in the final beer.
PHA®	PHA® products can suppress the bitter perception. We recommend PHA® Sylvan and Herbal with a start dosage of 10 g/hl.
Redihop®	Redihop® offers a very smooth bitterness and can be used as a post-fermentation product. For approx. 6 IBU use 2.5 g/hl and reduce the bitterness on the hot side accordingly.

Craft-type NA beers	
SPECTRUM	For a pleasant bitterness shift some of the IBUs from boiling to the cold side. Start with 10 g/hl of SPECTRUM at end of fermentation. With higher additions the aroma impact will become more dominant.
PRYSMA®	A good addition to the body are the use of liquid extracts. PRYSMA® might be preferred over SPECTRUM in this case as it does not impart additional bitterness and the flavor impact is less than with SPECTRUM. Start with 15 g/hl of PRYSMA® in the final beer.
LupoMAX®/LupoCORE™	We would recommend using a certain amount of pellets as a late kettle and/or dry-hop addition. The vegetative flavor in low amounts helps the bitterness to integrate with the overall flavor. Start with a dosing of of 50–75 g/hl.
PHA®	PHA® products can suppress the bitter perception. We recommend PHA® Sylvan and Herbal with a start dosage of 10 g/hl.
Redihop®	Redihop® offers a very smooth bitterness and can be used as a post-fermentation product. For approx. 6 IBU use 2.5 g/hl and reduce the bitterness on the hot side accordingly.

THE CHALLENGE:

UNWANTED AROMAS (DIACETYL, ACIDS, LINGERING AND UNFRESH FLAVOR)

THE CAUSE:

Fermentation can lead to unwanted flavors depending on the raw materials and the yeast or other microorganisms in the process. There is still a lot you can do to change the final flavor of your NA beer.

POSSIBLE SOLUTIONS:

Acidification to pH < 4.5, check yeast vitality, reduce gravity, sufficient carbonation

PRODUCT SOLUTIONS:

Lager-type NA beers	
PRYSMA®	To suppress unwanted aromas start with 10 g/hl of PRYSMA®.
PHA® Topnotes / PHA® Classics	PHA® Sylvan, Floral and Spicy are recommended to suppress unwanted aromas. Start with 10 g/hl of product. With a chosen variety of PHA® Top Notes you can additionally suppress other flavors, also here start with 10 g of product/hl. As the impact is matrix dependent increase dosage until the aroma impact is as you need it.
LupoMAX®/LupoCORE™	Depending on the hop variety and oil content of LupoMAX® aim for 2 ml of hop oil/hl (either all in the whirlpool or split 1/3 in the whirlpool and 2/3 for Dry Hopping). If you add more or other hop products at a later process point reduce accordingly. Be aware that the use of pellets can lead to hop creep and with this to a second production of diacetyl.

Craft-type NA beers	
SPECTRUM	To suppress unwanted flavors start with 20 g/hl of SPECTRUM at end of fermentation. If you add more or other hop products at a later process point reduce accordingly.
PRYSMA®	To suppress unwanted aromas start with 20 g/hl of PRYSMA®.
LupoMAX®/LupoCORE™	Depending on the hop variety and oil content of LupoMAX® aim for 4 ml of hop oil/hl (either all in the whirlpool or split 1/3 in the whirlpool and 2/3 for Dry Hopping). If you add more or other hop products at a later process point reduce accordingly. Be aware that the use of pellets can lead to hop creep and with this to a second production of diacetyl.
PHA®	PHA® Sylvan, Floral and Spicy are recommende to suppress unwanted aromas. Start with 10 g/hl of product. With a chosen variety of PHA® Top Notes you can additionally suppress other flavors, also here start with 10 g of product/hl. As the impact is matrix dependent increase dosage until the aroma impact is as you need it.
HopHaze®	If you are looking for a hazy non-alcoholic beer this product will deliver a constant haze and additionally will add some mouthfeel and support aroma. Start with a dosing of 50 g/hl.

USEFUL INFORMATION

ABOUT NON-ALCOHOLIC AND LOW-ALCOHOL BEERS

THE DEFINITION OF NON-ALCOHOLIC BEER

The definition of non-alcoholic beers is not harmonized within the European Union. Instead of a uniform regulatory requirement, there are different national limit values, which are both historical and legislative. The majority of Member States use an alcohol limit of ≤ 0.5% vol as the basis for the designation 'non-alcoholic'. This category includes Germany, Austria, Poland, Belgium, the Czech Republic and other countries.

Table 1: Permitted alcohol content for low-alcohol and non-alcoholic beers (incomplete excerpt 23.3.2026, information without guarantee)

Beer type	Min-Max alcohol content and % (v/v)	Exceptions (alcohol content in % (v/v)
low-alcohol beer	0.5–1.2%	<1 Nigeria
		< 2.25 Sweden
		<2.5 US
		<2.75 Norway
		<2.8 Denmark
		<3 Spain
		<3.7 Finland
non-alcoholic beer	<0.5	0.0 Islamic countries
		<0.05 Great Britain
		<0.1 Netherlands, Denmark
		<0.4 Canada
		<0.7 Norway
		<1 Spain, Japan
		<1.2 France, Italy, Slovenia
		<2,25 Island
		<2.8 Finland

At the same time, several countries deviate significantly from this standard. A particularly strict interpretation can be found in the Netherlands, where non-alcoholic beer is only considered as such if it contains ≤ 0.1% vol. Also noteworthy is the regulation in Ireland, where a limit of ≤ 0.05% vol. is applied. Both countries define the term "alcohol-free" much more restrictively than the majority of EU countries.

At the other end of the SPECTRUM are countries whose maximum permitted levels for the designation 'non-alcoholic' are significantly higher than those of most Member States. In Spain, the threshold is ≤ 1.0% vol., while France and Italy even provide for limits of ≤ 1.2% vol. Products that are marketed as alcohol-free in these countries thus sometimes significantly exceed the values accepted in many other countries.

These differences lead to an inconsistent legal framework across the European Union, which has implications for labeling, cross-border distribution and consumer expectations. A beer that is legally considered alcohol-free in one Member State may be classified as alcoholic in another. The regulatory framework and the large number of names for non-alcoholic and low-alcohol beers lead to considerable challenges within the European Union. The European Commission points out that consumers are often unsettled by heterogeneous terms such as "alcohol-free", "non-alcoholic" or "0.0". In particular, there is a risk that consumers will not be able to clearly identify whether a product marketed as alcohol-free nevertheless contains small amounts of alcohol. The lack of harmonization makes both market transparency and the comparability of products within the internal market more difficult.

A LOOK IN THE PAST AND IN THE FUTURE

Since when has non-alcoholic beer actually existed?

The different definitions make it clear that the difference between non-alcoholic beer and low-alcohol beer cannot always be clearly drawn. If we turn to the history of non-alcoholic beer, we cannot ignore the low-alcohol beer. Low-alcohol beer has been around for as long as alcoholic fermentation has existed. For thousands of years, the absolute alcohol content was firstly not measurable and secondly not important, it was about the production of beverages that could be consumed safely compared to polluted/contaminated drinking water. Especially in the monastery breweries of the Middle Ages, low-alcohol beer was continuously produced, among other things for pilgrims, but also for self-catering and especially for Lent. The production of "quasi" alcohol-free beer became important during Prohibition in the USA (1919–1933). Here, an unfermented malt drink with <0.5% alcohol was produced and sold as "Near Beer". The technical dealcoholization of beer is a comparatively recent development in the history of brewing. While low-alcohol beers were already produced in isolated cases in the 19th century by adapted or prematurely terminated fermentation processes, for a long time there was no industrial possibility of removing alcohol from already fermented beer in a targeted and reproducible manner. Carl von Linde, a German engineer and pioneer of refrigeration technology, developed the first dealcoholization system for subsequent alcohol removal in 1908, marking the beginning of modern dealcoholization technology in the brewing industry.

The process developed by Linde was based on the principle of vacuum distillation. By lowering the ambient pressure, the boiling point of ethanol could be significantly reduced, so that the alcohol evaporated from the beer at comparatively low temperatures. For the first time, this made it possible to remove alcohol in a technically controlled manner without having to put a heavy thermal load on the product or completely redesign the brewing process. Compared to earlier methods, in which alcohol production was merely avoided or restricted, this method represented a fundamental paradigm shift.

The introduction of the dealcoholization plant in 1908 created the prerequisites for the industrial production of non-alcoholic beer in today's sense. It made it possible to produce a fully fermented and sensorially developed beer and to remove the alcohol only in a downstream process step.

However, it was not until the 1980s that physical processes such as vacuum distillation were widely used to remove alcohol. Before maltose-negative yeasts became established in recent years, many breweries used a combination of dealcoholization and stopped fermentation to compensate for the sensory disadvantages in the best possible way.

Regardless of the production method, alcohol-free beer is rich in valuable micronutrients such as vitamins of the B-complex, minerals, polyphenols and secondary plant substances. These ingredients contribute to antioxidant, anti-inflammatory and potentially functional properties, which increasingly positions non-alcoholic beer in the context of sports, regeneration and wellness.

Table 2: Minerals in non-alcoholic beer (Ruggiero 2025)

Mineral	Concentration (mg/L or µg/L)	Recommended daily intake
Calcium	35–40 mg/L	800–1000 mg
Iron	Trace – 0.2 mg/L	8 mg
Magnesium	100–110 mg/L	300–350 mg
Phosphorus	300–400 mg/L	1250–1500 mg
Potassium	200–600 mg/L	4700 mg
Sodium	30–32 mg/L	550–1500 mg
Zinc	Trace – 0.12 mg/L	9.4 mg
Copper	Trace – 0.05 mg/L	0.7 mg
Manganese	Trace – 0.08 mg/L	2.3 mg
Sulfate	150–200 mg/L	no information
Selenium	4–7 µg/L	45 µg

Table 3: Vitamins in non-alcoholic beer (comparative presentation)

Vitamin	Rec. Daily intake	Content in standard beer (per L)	Content in non-alcoholic beer (per L)
Niacin (B3)	17 mg	7.7 mg	8.45 mg
Pyridoxine (B6)	1.5 mg	0.619 mg	0.61 mg
Cobalamin (B12)	3 µg	0.82 µg	0.7 µg
Pantothenic acid (B5)	6 mg	1.49 mg	0.74 mg
Folic acid (B9)	0.4 mg	86 µg	97 µg
Riboflavin (B2)	1.5 mg	0.335 mg	0.370 mg
Biotin (B7)	60 µg	12 µg	15 µg
Thiamin (B1)	1.3 mg	29 µg	23 µg

Non-alcoholic beer provides in particular relevant amounts of vitamins B3, B2, B9 as well as minerals such as magnesium, potassium and phosphorus. These values are nutritionally very interesting.

CONCLUSION AND PERSPECTIVE

From a brewing science perspective, research into the biodiversity of non-conventional yeasts opens up a promising path for the natural production of non-alcoholic beers. So far, only a small fraction of naturally occurring yeasts have been characterized, suggesting that there are many more strains with interesting technological properties to be discovered, such as unique biotransformation capabilities, aldehyde degradation, or interactions with hop varieties.

By using maltose-negative yeasts, we're not just making "beer without alcohol" – we're creating a new category of fermented beverages that respects the integrity of traditional brewing while meeting modern consumer demands. The ideal partner for the yeasts is hops. It brings with it what a full-bodied, hoppy taste experience would otherwise be missing. There are no limits to the combination of hop varieties and hop products.

For years, it has been discussed whether this comparison to alcoholic beers is good for these beers, or whether it doesn't make much more sense to use these beers alone for the manifold positive properties, valuable ingredients, special taste properties, etc. Perhaps then the term beer is no longer expedient, but it could be about malt-based beverages with additional benefits.

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TECHNICAL SUPPORT At BarthHaas we have a dedicated team that are able to advise customers on all hop-related brewing matters. If you have any further questions about optimizing flavor in non-alcoholic and low-alcohol beers we will be happy to help.

Please visit **BarthHaas.com** for more information or contact Brewing Solutions directly at **brewingsolutions@barthhaas.de**

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LITERATURE

Bellut, K., & Arendt, E. K. (2019). Chance and Challenge: Non-Saccharomyces Yeasts in Nonalcoholic and Low Alcohol Beer Brewing – A Review. Journal of the American Society of Brewing Chemists, 77(2), 77–91. https://doi.org/10.1080/03610470.2019.1569452

Bohak, I. et al: Selected Chapters of Brewing Technology, HCV, 2005 Nuremberg

Brendel S, Hofmann T, Granvogl M. Dry-Hopping to Modify the Aroma of Alcohol-Free Beer on a Molecular Level-Loss and Transfer of Odor-Active Compounds. J Agric Food Chem. 2020 Aug 12; 68(32):8602-8612. doi: 10.1021/acs.jafc.0c01907. Epub 2020 Jul 28. PMID: 32657584.

Britton, S. J., & Hill, A. E. (2025). Microbiological Quality Control in Non- and Low-Alcoholic Beer Manufacturing: A Comprehensive Review of Microbial Contaminants and Strategies for Spoilage Prevention. Journal of the American Society of Brewing Chemists, 83(4), 365–382. https://doi.org/10.1080/03610470.2025.2508612

Ruggiero M, Mercurio N, Ferrante L, Scudiero O, Mazzeo F. Craft Non-Alcoholic and Low-Alcohol Beer (NABLAB): Perceived Role as Functional Foods Among Italian Consumers and a Focus on Benefits for Well-Being and Physical Activity. Nutrients. 2025 Dec 21; 18(1):33. doi: 10.3390/nu18010033. PMID: 41515151; PMCID: PMC12787960.

Sönke Kienitz, Hubert Kollmannsberger, Annsophie Schreff, Dennis Mayer, Christoph Neugrodda, Thomas Becker,Impact of different production methods on selected aroma compounds for non-alcoholic beers by developing an HS-SPME GC–MS method,Food Chemistry,Volume 504,2026,147924,ISSN 0308-8146, https://doi.org/10.1016/j.foodchem.2026.147924

Wolinska-Kennard K, Schönberger C, Fenton A, Sahin AW. Mouthfeel of Food and Beverages: A Comprehensive Review of Physiology, Biochemistry, and Key Sensory Compounds. Compr Rev Food Sci Food Saf. 2025 Jul; 24(4):e70223. doi: 10.1111/1541-4337.70223. PMID: 40625310; PMCID: PMC12235588.

Karaoğlan, S.Y., Jung, R., Jelínek, L., Karabín, M., Kinčl, T. and Dostálek, P. (2025), "Aroma Potential of a New Maltose-Negative Yeast Isolate", Foods, Vol. 14 No. 19, p. 3357, doi: 10.3390/foods14193357.

Salanță, L.C., Coldea, T.E., Ignat, M.V., Pop, C.R., Tofană, M., Mudura, E., Borșa, A., et al. (2020), "Non-Alcoholic and Craft Beer Production and Challenges", Processes, Vol. 8 No. 11, p. 1382, doi: 10.3390/pr8111382.

Simon, M., Christiaens, R., Janssens, P. and Collin, S. (2024), "Unexpected Behavior of a Maltose-Negative Saccharomyces cerevisiae Yeast: Higher Release of Polyfunctional Thiols from Glutathionylated Than from Cysteinylated S-Conjugates", Fermentation, Vol. 10 No. 6, p. 276, doi: 10.3390/fermentation10060276.

Yabaci Karaoglan, S., Jung, R., Gauthier, M., Kinčl, T. and Dostálek, P. (2022), "Maltose-Negative Yeast in Non-Alcoholic and Low-Alcoholic Beer Production", Fermentation, Vol. 8 No. 6, p. 273, doi: 10.3390/fermentation8060273.