HAMK
Häme University
of Applied Sciences

Brewery Side Stream Yeast

Utilization and Processing for Food Industry Applications

Bachelor's Thesis
Degree Programme in Biotechnology and Food Engineering
Spring 2025
Kaisa Levänen

HAMK
Häme University
of Applied Sciences

Bio- ja elintarviketekniikan koulutusohjelma		Tiivistelmä
Tekijä	Kaisa Levänen	Vuosi 2025
Työn nimi	Oluen valmistuksessa syntyvä sivuvirtahiiva –hyödyntäminen ja käsittely elintarviketeollisuudessa	
Ohjaaja	Juha Isokangas	

Tämän opinnäytetyön tarkoituksena oli tutkia oluen valmistuksessa sivuvirtana syntyvän ylijäämähiivan hyödyntämistä elintarvikealalla. Työn toimeksiantajana oli HÄMILIS: Hävikki Minimiin, Lisäarvo Maksimiin -hanke, jonka tavoitteena on edistää elintarvikealan kestävää kehitystä Kanta- ja Päijät-Hämeessä käyttäen kiertotalouden toimintamalleja esimerkiksi sivuvirtojen hyödyntämiseen uusien tuotteiden raaka-aineena. Sivuvirtahiiva on suuren kosteuspitoisuutensa vuoksi erittäin herkästi pilaantuvaa, mikä tekee sen hyödyntämisestä haastavaa. Kuivaaminen on tehokas säilömismenetelmä, mutta sillä voi olla negatiivisia vaikutuksia esimerkiksi ravintoarvoihin ja hiivan toimintakykyyn. Opinnäytetyössä selvitettiin sivuvirtahiivan sisältämiä, elintarviketeollisuuden näkökulmasta kiinnostavia arvojakeita sekä tutkittiin kuivaamisen ja säilytysolosuhteiden vaikutusta hiivan toimintakykyyn ja jatkokäyttömahdollisuuksiin.

Sivuvirtahiivan koostumusta sekä hyötykäyttöä elintarviketeollisuudessa selvitettiin kirjallisuuden ja aiemman tutkimustiedon perusteella. Lisäksi kuivaamisen ja säilytysolosuhteiden vaikutuksiin liittyen tehtiin käytännön koe, jossa kaupallisesta panimohiivasta, vedestä ja panimosokerista valmistetusta seoksesta kerättyä hiivamassaa kuivattiin eri menetelmillä: uunissa, hyötykasvikuivurilla sekä pakkaskuivaamalla. Kuivauksen jälkeen hiivan toimintakykyä arvioitiin aktivoimalla hiiva lämpimässä vedessä. Kuivatuista hiivanäytteistä osa säilytettiin pakastimessa ja osa huoneenlämmössä viikon ajan, jonka jälkeen hiivan toimintakykyä testattiin jälleen aktivoimalla lämpimässä vedessä. Lisäksi hiivasoluja tutkittiin mikroskoopilla.

Kaikkien käytännön kokeessa käytettyjen kuivausmenetelmien voitiin todeta vaikuttaneen negatiivisesti hiivan toimintakykyyn. Lisäksi pakkaskuivatussa hiivassa havaittiin voimakas panimosokerin tuoksu. Eri säilytysolosuhteilla ei tällä aikavälillä ja käytössä olleilla tutkimusmenetelmillä havaittu selvää vaikutusta hiivan toimintakykyyn.

Tutkimustulosten perusteella voidaan todeta, että sivuvirtahiiva on erittäin proteiinipitoista, ja sisältää monia elintarviketeollisuuden näkökulmasta arvokkaita yhdisteitä, kuten aminohappoja ja β-glukaaneja. Voidaan myös todeta, että kuivaaminen on tehokas tapa säilöä hiivaa, kunhan kuivausmenetelmä valitaan halutun käyttökohteen perusteella ja kuivausprosessi on hallittu. Lisäksi on suositeltavaa poistaa hiivasta käymisprosessin jäämät, sillä ne saattavat aiheuttaa lopputuotteessa ei-toivottuja hajuja tai makuja.

Avainsanat Sivuvirtahiiva, sivuvirtojen hyödyntäminen, elintarviketeollisuus, hiivan kuivaaminen
Sivut 26 sivua ja liitteitä 1 sivu

HAMK
Häme University
of Applied Sciences

Degree Programme in Biotechnology and Food Engineering		Abstract
Author	Kaisa Levänen	Year 2025
Subject	Brewery Side Stream Yeast –Utilization and Processing for Food Industry Applications	
Supervisor	Juha Isokangas	

This thesis was commissioned by the HÄMILIS: Waste to a Minimum, Added Value to a Maximum - project. The project seeks to promote sustainable development in the food industry in Kanta- and Päijät-Häme regions using circular economy operating models, such as utilization of side streams as material for new products. The goal of this thesis was to study utilization of a side stream of beer production, brewer's spent yeast (BSY), in the food industry. Due to its high moisture content, BSY is highly perishable making utilization in food products challenging. Drying is an effective method of preservation, but it might have a negative effect on nutritional values and yeast viability. The aim of this thesis was to study components of BSY valuable for food industry and to examine the effects of drying and storage conditions on yeast viability and utilization possibilities.

In the thesis, the composition and food industry utilization of BSY was studied based on literature and previous research data. Additionally, to examine the effects of drying and storage conditions, a practical experiment was conducted. Commercial brewer's yeast was mixed with brewing sugar and water, and the yeast mass harvested from the mixture was dried by different methods: in an oven, in a food dehydrator and in a freeze dryer. After drying, yeast viability was tested by activating the yeast in warm water. Some of the dried yeast samples were stored at room temperature and others in a freezer for one week, and the yeast viability was tested by activating the yeast in warm water and examining the yeast cells with a microscope.

It was observed that every drying method used in the practical experiment had a negative effect on yeast viability. Additionally, the freeze-dried yeast had a very distinct smell of brewing sugar. The storage conditions had no notable effects on the yeast samples during this experiment.

Based on the results of this study it can be concluded that BSY is high in protein and contains many compounds valuable for food industry, such as amino acids and β-glucans. Furthermore, it can be concluded that drying is an effective method for preserving yeast if the drying method is chosen based on desired application and the drying process is managed carefully. It might be recommendable to remove any residues left from the brewing process before drying to avoid any unwanted odors or flavors in the final product.

Keywords Brewer's spent yeast (BSY), utilization of side streams, food industry, yeast drying
Pages 26 pages and appendices 2 pages

Table of Contents

Figures

Tables

Equations

Appendices

1 Introduction

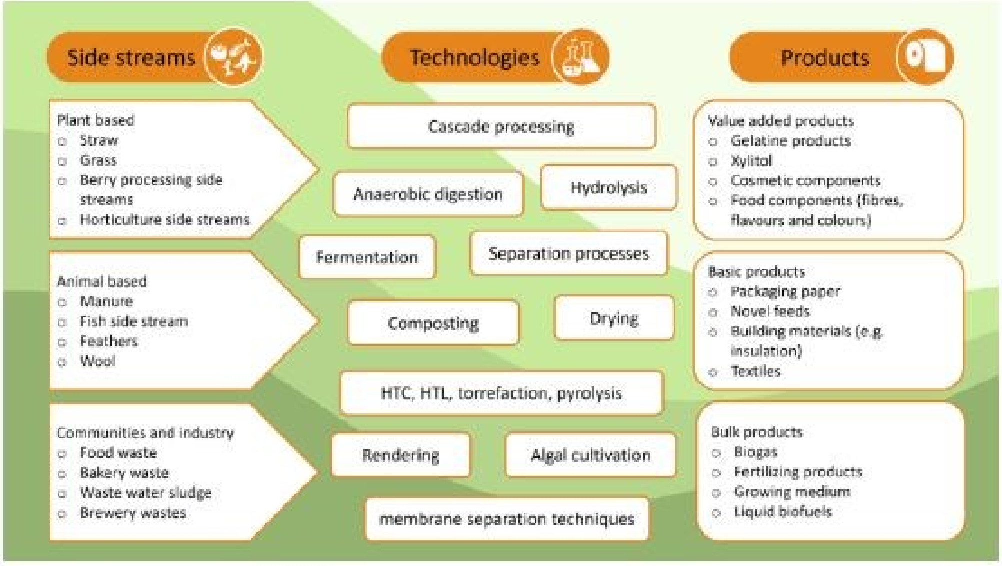
This thesis work is commissioned by the HÄMILIS: Waste to a Minimum, Added Value to a Maximum- project. The project partners are Häme University of Applied Sciences (HAMK), LAB University of Applied Sciences and Häme Vocational Institute (HAMI) and the main target group is food companies in the grain and beverage sector in Kanta- and Päijät-Häme regions. The project seeks to find new innovations and create cooperation between operators in the field. Principles of the circular economy, such as efficient utilization of side streams, offer companies the opportunity to reduce waste and increase economic profitability in ways that promote sustainable development. (HAMK, n.d.)

The circular economy is a model of production and consumption that aims to reduce the amount of waste as much as possible. This can be done, for example, by using raw materials efficiently. In addition to the environmental benefits of waste reduction, the circular economy could boost economic growth and create new jobs, for new products require innovation and design. (European Parliament, 2023).

Waste reduction and efficient use of raw materials can be achieved by utilizing side streams. Side streams are material or energy flows formed in a production process while not being the main product (Natural Resources Institute Finland, n.d.). Side stream utilization is a good way for companies to participate in sustainable development and in achieving The Sustainable Development Goals. The 17 Sustainable Development Goals adopted by the United Nations in 2015 are integrated meaning that action in one area affects the outcome in others. Environmental, social and economic sustainability must be considered equally. (United Nations Development Programme, n.d.)

By utilizing side streams, companies can simultaneously reduce waste production and improve economic growth, promoting both environmental and economic sustainability. Side stream utilization requires new innovations and solutions, and therefore is likely to increase employment, which promotes social sustainability. Side streams can be used to produce renewable energy or more sustainable products. Figure 1 presents examples of three different side streams, various methods for utilizing them and possible end products.

Figure 1. Examples of side stream utilization. (Natural Resources Institute Finland (Luke), n.d.)



The goal of this thesis is to study the possibilities of utilizing brewer’s spent yeast in food industry applications. Brewer’s spent yeast (BSY) is the second largest side stream originated from beer production. BSY contains a lot of proteins, vitamins and minerals, and has a lot of potential to be used in food industry applications.

There are some notable challenges in utilization of BSY, one main issue being the high moisture content of BSY, making it highly perishable. For utilization, especially in the food industry, BSY requires either proper treatment or storing. Drying is a good method for preserving, since storage and transport costs are low for dried products. However, drying might have a negative effect on nutritional values and other product qualities. (Saarela, 2010, pp. 292–293) In case of yeast, drying could be detrimental to yeast’s viability. Yeast viability means the ability of yeast cells to grow and reproduce (Goldammer, 2022, chapter 4, paragraph 1). Maintaining yeast viability is essential in some food industry applications for BSY.

This thesis is built on the following research questions:

- What are the most important compounds in brewer’s spent yeast that are valuable for the food industry?
- How do different drying methods affect yeast viability?
- Do storage conditions have significant effect on yeast viability?

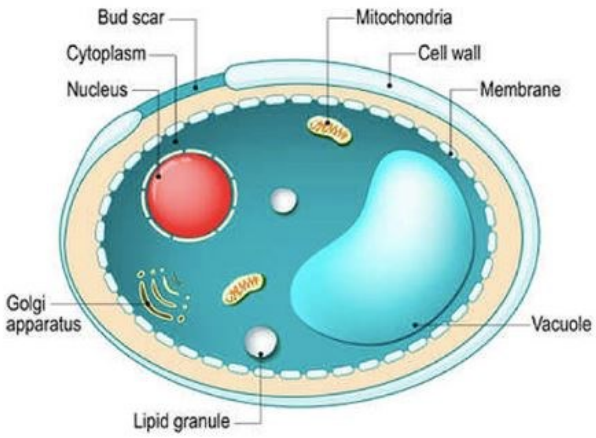
The research questions are answered based on literature, previous research data and other reliable information available on the subject. Additionally, practical tests are carried out regarding the effects of drying and storage conditions on yeast viability.

2 Brewer’s yeast and the brewing process

Yeasts are single-celled fungi, and they exist in various kinds of environments. There are numerous species of yeast with different characteristics. Brewer’s yeasts belong to the taxonomic family *Saccharomycetaceae,* genus *Saccharomyces.* Brewer’s yeasts are mostly strains of *Saccharomyces cerevisiae* or *Saccharomyces pastorianus* (Walker, 1998, p. 285).

Yeasts commonly reproduce by budding. A new so-called daughter cell starts to grow out of mother cell. Once the daughter cell has grown into full size, it usually separates from the mother cell. This leaves a bud scar on the cell wall of the mother cell, and a birth scar on the cell wall of the daughter cell (Walker, 1998, p. 23). In figure 2, an illustration of a yeast cell shows a bud scar on the yeast cell wall, alongside with other features of a yeast cell.

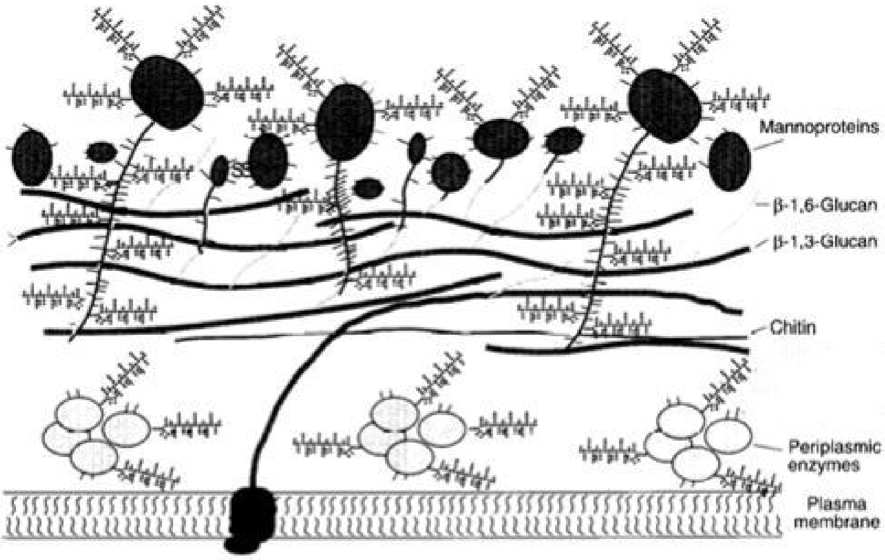
Figure 2. Yeast cell. (AngelYeast Co., Ltd, n.d.)



Yeast cells are eukaryotic, so they have a membrane bound nucleus containing chromosomes. The nuclear membrane separates the nucleus from the cytoplasm. Cytoplasm is an acidic colloidal fluid containing compounds of low and intermediate molecular weights (Walker, 1998, p. 29). Lipid granules are suspended in the cytoplasm (Walker, 1998, p. 29). Mitochondria have both respirational and non-respirational functions in the cell. Golgi apparatus is involved in protein trafficking (Walker, 1998, p. 35). Vacuoles are important organelles in protein trafficking inside the yeast cell (Walker, 1998, p. 37).

The yeast cell is surrounded by a cell wall. The cell wall is a significant structural feature making yeast cells different from animal cells (Walker, 1998, p. 19). The cell wall is mainly composed of polysaccharides, glucans and mannans being the most prominent. Yeast cell wall also contains chitin, approximately 2–4 % in *S. cerevisiae*, mostly in bud scars. (Walker, 1998, p. 22). The cell wall has two layers. The outer layer is made up of mannoproteins, and most of them are covalently linked to the inner layer. The inner layer consists of β-1,3- and β-1,6-glucan and chitin. Periplasmic enzymes are confined between the inner layer and the plasma membrane. (Schreuder et al., 1996, p. 116) Composition and structural components of the yeast cell wall are presented in figure 3.

Figure 3. Composition and structure on the yeast cell wall. (Adapted from Schreuder et al., 1996, p. 116)



2.1 Characteristics of brewer’s yeasts

Yeasts can be categorized into wild yeasts and culture yeasts. Wild yeasts grow in nature on their own without human involvement and culture yeasts are cultivated on purpose for a specific function. Brewer’s yeast, baker’s yeast and wine yeast are examples of culture yeasts. Most culture yeasts can ferment sugars in anaerobic conditions (Enari & Mäkinen, 2014, pp. 112–113)

Brewer’s yeasts can be classified into top- and bottom-fermenting yeasts. Top-fermenting yeasts are strains of *S. cerevisiae* and are used to brew top-fermented beers such as ale. According to its name, top-fermenting yeasts will rise on the surface at the end of fermentation contrary to bottom-fermenting yeast, which will settle to the bottom. Lager is the most common type of bottom-fermented beer, and bottom-fermenting brewer’s yeasts are strains of *S. pastorianus*. (Enari & Mäkinen, 2014, p. 113) In literature, *S. pastorianus* can be referred to by its old names *Saccharomyces carlsbergensis* or *Saccharomyces uvarum* (Ferreira et al., 2010, p. 78).

Sugars are the most suitable energy sources for yeasts. Glucose, fructose, sucrose, maltose, maltotriose and raffinose are fermentable, meaning they can be utilized by brewer’s yeasts. Some carbohydrates, including lactose, starch and cellulose are not fermentable. (Enari & Mäkinen, 2014, p. 115)

Brewer’s yeasts are facultative, meaning life and reproduction is possible both in and without the presence of oxygen. The yeast growth is more efficient when oxygen is present, but more alcohol is formed in anaerobic conditions. (Enari & Mäkinen, 2014, p. 116)

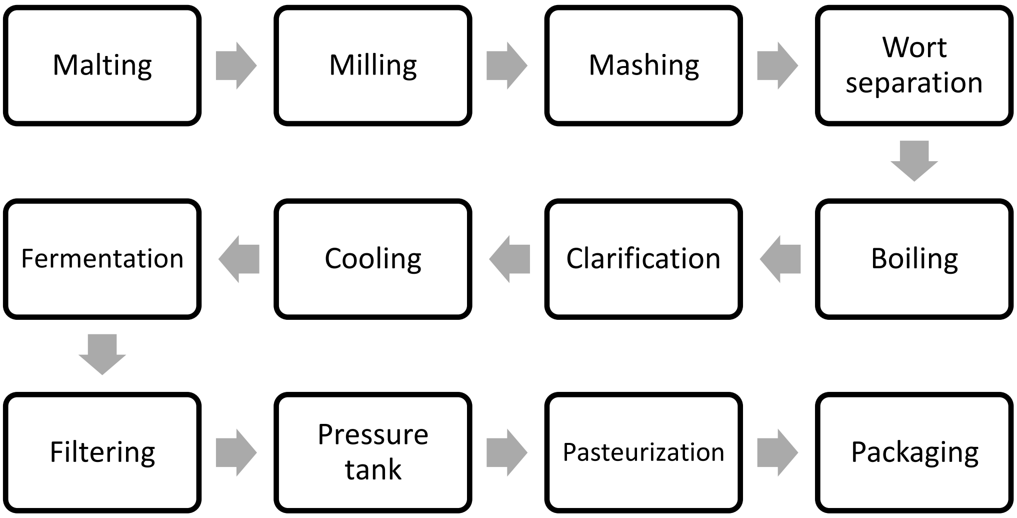
Based on temperature requirements, brewer’s yeasts are classified as mesophilic. Optimal temperature for growth and fermentation for brewer’s yeasts is between 25 and 30 °C, but the actual temperature range is large. Growth slows down at 40 °C and cell death occurs at 60 °C. (Enari & Mäkinen, 2014, p. 117)

Flocculation is important for the brewing process. Flocculation is the word used for the phenomenon of yeast cells gathering forming flocks. These flocks vary in size and the larger the flock, the faster it will sink in liquid. Yeast strains flocculate differently, and brewer’s yeasts can be divided into four groups based on flocculation. First group is non flocculent yeasts, and like the name suggests, they do not form flocks. Yeasts in the second group slowly form small and loose flocks, yeasts in the third group form tight flocks of various sizes in a late state of fermentation and yeasts in the fourth group flock at an early stage of fermentation forming large and tight flocks. (Enari & Mäkinen, 2014, pp. 117–118)

2.2 The brewing process

Malts, hops, yeast and water are the main ingredients used in beer production. The process may vary slightly according to the type of beer being brewed, but the basics stay the same. The flow chart of the basic brewing process shown in figure 4 was created based on brewing process flow charts by Quain & Boulton (2001, p. 30) and Sinebrychoff (n.d.-a).

Figure 4. The basic brewing process. (Adapted from Quain & Boulton, 2001, p. 30; Sinebrychoff, n.d.-a)



The first step of the brewing process is malting, and it takes place in a malthouse. During malting barley grains are first wetted to start germination, which is then stopped by drying the grains using hot air. The purpose of malting is to ensure release of fermentable sugars during the preparation of wort. (Enari & Mäkinen, 2014, pp. 22–23; Quain & Boulton, 2001, p. 30) In this thesis the focus is on barley, but other cereals can also be used in beer making.

After malting, the malts are transported to a brewery where the malts are ground into grist. This is called milling. Next step is mashing, when water is added to the grist and the mixture is heated to produce sweet wort. (Quain & Boulton, 2001, p. 37) Wort separation means separating the spent grains from the sweet wort by filtration (Enari & Mäkinen, 2014, p. 102). Next step is boiling of the sweet wort. Hops are added during boiling. Adding of hops can happen at different stages of boiling depending on the type of beer being brewed. (Enari & Mäkinen, 2014, pp. 105–106) After boiling, the wort is clarified by removing solids formed during boiling, called trub, and hop residues. (Quain & Boulton, 2001, p. 43) The wort is cooled down and aerated (Enari & Mäkinen, 2014, p. 110).

During fermentation, the yeast turns the sugars in the wort into carbon dioxide and alcohol. Fermentation is described in more detail in section 2.3 Fermentation.

Stabilization is done to prevent the beer becoming unclear and muddy. Stabilization can be done by using stabilizers and keeping the beer at cold temperature before filtration. (Enari & Mäkinen, 2014, p. 171) Remaining yeast is removed from the beer by filtration (Enari & Mäkinen, 2014, p. 172). Commonly used methods are separation and siliceous earth filtering, also known as kieselguhr filtering, as preliminary filtration methods, followed by disc or membrane filtration (Enari & Mäkinen, 2014, p. 173).

Filtrated beer is lead to a pressure tank or after disc pasteurization (Enari & Mäkinen, 2014, p. 183). Beer is pasteurized for biological preservability. Disc pasteurization is carried out before packaging, or tunnel pasteurization is used, meaning the beer is packaged before being pasteurized in sealed packages. (Enari & Mäkinen, 2014, p. 181).

2.3 Fermentation

Fermentation can be divided into two phases, main fermentation and storage fermentation. Fermentation takes place in a fermenter, which is generic term for vessels used for fermentation. Different types of fermenters can be used in brewing. Fermentation tanks used in breweries are usually cylinder shaped with a round or conical bottom. Fermentation tanks are typically made of stainless steel and are available in variety of sizes for different production volumes. (Enari & Mäkinen, 2014, pp. 146–148)

Conical-bottomed fermentation tanks are widely used in breweries. The conical part and the tank are surrounded by cooling jackets. The tank has a temperature gauge for monitoring the temperature, and it can be adjusted to vary in different parts of the tank. For pressure control, the tank has a pressure gauge and control system. Carbon dioxide input and recovery and a sample valve are included. The yeast is removed from the tank through the drain outlet located in the bottom of the tank. (Enari & Mäkinen, 2014, pp. 147–148)

Figure 5 is of a conical fermentation tank. In addition to parts and features mentioned earlier, the tank in the picture has a dry hopping port. Dry hopping means that hops are added into the fermentation tank during main fermentation (Goldammer, 2022, chapter 12, topic 5).

Figure 5. Conical fermentation tank. (Carry Brewtech, n.d.)

Conical fermentation tanks are suitable for main fermentation, but it is common that the whole fermentation process is carried out in the conical fermentation tank (Enari & Mäkinen, 2014, p. 146). Universal tanks known as Uni-tanks can be described as an intermediate between conical and round fermentation tanks (Enari & Mäkinen, 2014, p. 146). They are not considered as effective as conical fermentation tanks from characteristics point of view, but they are cost-efficient and can also carry out main and storage fermentation (Enari & Mäkinen, 2014, p. 148).

Round-bottomed fermentation tanks are not as commonly used in main fermentation due to difficult yeast removal after fermentation. However, they are suitable for main fermentation of non-flocculent yeasts when separator is used to remove the yeast. Round-bottomed tanks can be used in storage fermentation in case main and storage fermentation are carried out in separate vessels. (Enari & Mäkinen, 2014, p. 148) In some breweries, traditional open fermenters are still used for main fermentation. Storage fermentation is always carried out in a closed fermenter. (Enari & Mäkinen, 2014 p. 145)

To start the fermentation, yeast is added to aerated wort that has been cooled down to a lower temperature than during main fermentation. The temperature during main fermentation is at 18–25 °C for top-fermenting yeasts and below 16 °C for bottom-fermenting yeasts. (Enari & Mäkinen, 2014, pp. 148–149) Oxygen is necessary for the yeast growth in the beginning of fermentation. When oxygen runs out, alcoholic fermentation begins. (Enari & Mäkinen, 2014, pp. 148-149) In brewing, the adding of yeast is called pitching.

During the first stage of main fermentation, the yeast adjusts to the conditions of the fermentation tank. The yeast activity increases until it reaches its highest point. In the final phase of main fermentation, the carbon dioxide formation starts to decline causing the foam to collapse, forming a dark brown layer on the top. Main fermentation is completed in between seven and nine days. (Enari & Mäkinen, 2014, pp. 148–149)

After the main fermentation, the beer is referred to as green beer, and it has a bitter flavor to it. During storage fermentation, the flavor matures and softens. Storage fermentation takes place at a cool storage temperature, and its duration is a few days for top-fermented beers and between one and two weeks for bottom-fermented beers (Sinebrychoff, n.d.-a).

3 Brewer’s spent yeast

Brewer’s spent yeast (BSY) is one of beer production side streams. It is also known as surplus yeast or residual yeast. BSY is yeast mass formed during fermentation, and it is in a form of wet slurry, containing residues from the brewing process. The yeast slurry also contains beer termed barm ale, which is removed from the yeast slurry to be blended in with the beer in appropriate rate and time of the brewing process (Quain & Boulton, 2001, p. 457). Part of the yeast is kept for re-pitching future fermentations (Quain & Boulton, 2001, p. 455).

The act of collecting yeast from the fermenter is referred to as cropping, and it should be done as soon as possible after fermentation. The conditions in the fermenter, such as low amount of nutrients and high level of carbon dioxide and ethanol concentrations, can make the yeast deteriorate. (Quain & Boulton, 2001, p. 456; Goldammer, 2022, chapter 12, topic 10) Before yeast removal, the temperature in the fermentation tank should be lowered between 2 and 4 °C to avoid metabolic activity of the yeast (Quain & Boulton, 2001, p. 456). With bottom-fermenting yeasts, the low temperature speeds up the sinking of the yeast into the bottom of the vessel (Quain & Boulton, 2001, p. 457).

Yeast cropping methods vary based on the type of fermentation vessel being used. In case of top-fermenting yeasts, the yeast can be cropped from the top of an open fermenter. When an open fermenter is used with bottom-fermenting yeast, the beer is removed first after main fermentation and the yeast is then cropped from the bottom of the fermenter. From a conical bottomed fermenter, the yeast can be cropped from the bottom of the cone. (Goldammer, 2022, chapter 12, topic 10)

The yeast used in re-pitching should be collected from the part that contains the least amount of wort solids. The collected yeast will unavoidably contain some wort residue, especially in bottom-cropping systems (Quain & Boulton, 2001, p. 456). When top-cropping, the top layer is most contaminated with trub and disposed of. In bottom-cropping systems, the lowest layer is the most contaminated. For re-pitching, the yeast is collected from the middle of the yeast sediment. (Quain & Boulton, 2001, pp. 456–457) The yeast that is to be used in re-pitching, is collected into an appropriate container (Quain & Boulton, 2001, p. 457).

The yeast mass that is not needed or not suitable for re-pitching is moved into waste yeast storage vessels after the barm ale has been recovered from the yeast (Quain & Boulton, 2001, p. 460). This can be done by filtration, and the yeast cake is then removed from the filter (Quain & Boulton, 2001, p. 457). The yeast cakes are disposed of or stored in a refrigerated room at a temperature between 2 and 4 °C and used for re-pitching later (Quain & Boulton, 2001, p. 489).

Mostly, the yeast collected for re-pitching is stored as a slurry in yeast storage vessels. To remove bacteria, the yeast slurry is washed with acid. Phosphoric acid is most used, but tartaric, hydrochloric, nitric and sulphuric acids are also suitable. (Quain & Boulton, 2001, pp. 494–495) The storage temperature should be low, between 2 and 4 °C, so the yeast stays cool but does not freeze. The yeast storage vessels are kept in a room where high level of hygiene is maintained. (Quain & Boulton, 2001, pp. 489–491)

Collecting and keeping yeast for re-pitching is profitable. In addition to saving costs, recycled yeast usually has more effective fermentation abilities than new yeast. (Quain & Boulton, 2001, 476) However, it is necessary to introduce new yeast at some point. This is to prevent gradual changes in properties, such as flocculation, in the yeast. It is also possible that after many re-pitching the condition of the yeast starts to weaken. Depending on operating conditions yeast can be used for re-pitching 15–20 times in some breweries, while the appropriate number for re-pithing might be 5–10 in others. (Quain & Boulton, 2001, pp. 475–476)

Before re-pitching, the condition of the yeast must be assessed to make sure that it is free from microbial contamination. In addition, determining yeast viability is necessary for successful re-pitching. (Quain & Boulton, 2001, pp. 496–497) Common method for yeast viability assessment in breweries is to prepare a suitable dilution of yeast slurry and adding methylene blue into it. The methylene blue stains dead cells blue making it easier to distinguish them from living cells. The cells are then counted using a cell counting chamber and a microscope. (Quain & Boulton, 2001, pp. 497–498)

3.1 Composition

The nutritional and chemical composition of BSY vary according to such factors as the yeast strain used, processing conditions during fermentation and brewing process, the time when the yeast mass is collected and how many times the yeast has been used for re-pitching (Marson et al., 2020, pp. 4–5). The composition of yeast biomass is presented in table 1.

Table 1. Percent composition of yeast biomass. (Adapted from Pacheco et al., 1997, p. 605)

Compound	Percentage of yeast biomass (%)
Protein	48.5
Ribonucleic acid (RNA)	7.5
Total lipids	3.4
Ash	8.3
Total carbohydrate	32.7
Total fiber	12.2

The average protein content of BSY is approximately 40–50 % (Mathias et al., 2015, pp. 401–402; Pacheco et al., 1997, p. 605; see also Zeko-Pivač et al., 2023, p. 3). In yeast protein concentrates protein content can be more than 70 % (Pacheco et al., 1997, p. 604). Yeast proteins contain all the essential amino acids, glutamic acid, aspartic acid, leucine, lysine and alanine being some of the most abundant (Pacheco et al., 1997 p. 605). High RNA concentration makes BSY a good source of nucleotides (Zeko-Pivač et al., 2023, p. 8).

BSY biomass contains a lot of B group vitamins, especially niacin (B3), thiamine (B1), pantothenic acid (B5) and riboflavin (B2) (Łukaszewicz et al., 2024, p. 7). Phosphorus, potassium, sodium, magnesium, calcium and zinc are the most abundant minerals in BSY (Marson et al., 2020, p. 4).

Carbohydrates in BSY are β-glucans, mannans and chitin, and major part of them are in the yeast cell wall (Łukaszewicz et al., 2024, p. 7). Table 2 shows the composition of yeast cell wall.

Table 2. Composition of yeast cell wall. (Adapted from Łukaszewicz et al., 2024, p. 7)

Cell wall	11–25 % of cell dry weight
β-glucan	32–57 % of cell wall
Mannan	28–67 % of cell wall
Chitin	1.4–6.9 % of cell wall

3.2 Applications

As a good source of proteins, minerals and vitamins, BSY is used in animal feed as a supplement. For example, the BSY from beer production of the Finnish brewing company Sinebrychoff is utilized in animal feed. Feed containing yeast is suitable for various animals, including pigs, calves, poultry, fish and shrimps, and it is an important export product. (Sinebrychoff, n.d.-b)

In human nutrition, yeast is usually dried or in a form of yeast extracts (Enari & Mäkinen, 2014, p. 260). For food safety, it is important to note the high content of nucleic acids, mostly ribonucleic acid (RNA), in BSY (Ferreira et al., 2010, p. 79). In humans, nucleic acids form uric acid, which is injurious to health. Yeast extracts can be produced in a way that they have lower concentrations of nucleic acids. (Enari & Mäkinen, 2014, pp. 260–261) There are methods for low RNA yeast protein isolation (Ferreira et al., 2010, p. 79).

BSY can be used in enzyme production. An example of an enzyme produced from yeast is invertase, used mainly in the sweets industry. (Enari & Mäkinen, 2014, p. 261) BSY can be utilized as a nitrogen source for production of lactic acids (Zeko-Pivač et al., 2023, p. 8).

Other possibilities for utilization include production of biofuels and wastewater treatment processes (Zeko-Pivač et al., 2023, p. 9).

3.3 Treatment and preservation

Due to its high moisture content, BSY is highly perishable and proper treatment and storing are essential for utilization in most applications. Before being transported from the brewery, the yeast slurry can be concentrated using filtration, yeast press or decanting centrifuge (Enari & Mäkinen, 2014, p. 260).

3.3.1 Drying

Drying is a traditional method for food preservation. The effect of drying is based on reducing chemical and microbiological reactions by removing water. Storage and transport costs for dried products are low, which is a significant advantage in drying as a preservation method. Drying may have negative effects on the material, so the drying method and conditions must be selected according to the desired outcome. For example, low drying temperature minimizes reductions of aroma and vitamin content. (Saarela, 2010, pp. 292–293)

Fluidized bed dryers are used for drying baker’s yeast. The wet yeast is sprayed into the dryer, and the small droplets dry in the hot air admitted from the bottom of the dryer. The dried droplets form larger granules, which will then fall into the collecting pipe below. The finer material floats in the hot air until the particles grow large enough to fall. This method is suitable for drying yeast suspension. (Saarela, 2010, p. 295)

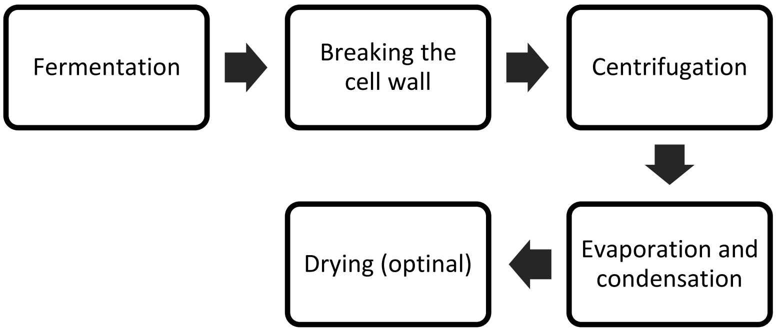
Freeze drying, also known as lyophilization, is an industrially used method in preserving yeast. Freeze dryer removes water from frozen material by sublimation. Drying is conducted at a low temperature in a vacuum. Freeze drying preserves properties, such as flavor, aromas and nutrients, better than air drying, but the driers are typically expensive or of low efficiency and therefore not suitable for large production volumes. (Saarela, 2010, pp. 294–295)

3.3.2 Yeast extracts

BSY can be used in production of yeast extract. Yeast extract contains all the components from the yeast cell without the cell wall. Yeast extracts can be used in soups, sauces and ready meals to improve the taste, but also to increase the protein content in the food. (European Association for Specialty Yeast Products, 2023a)

According to the European Association for Specialty Yeast Products (EURaSYP) (2023b), production of dried yeast extract consists of five steps: fermentation, breaking the cell wall, centrifugation, evaporation and condensation followed by drying as the final step (figure 6). In case the yeast extract is in a liquid form, the drying is not carried out. (EURaSYP, 2023b)

Figure 6. Main steps in yeast extract production process. (Adapted from EURaSYP, 2023b)



First, the yeast is grown in a fermenter at temperature of 30 °C. The yeast mass is then washed to remove residues and concentrated in a centrifuge. (EURaSYP, 2023b)

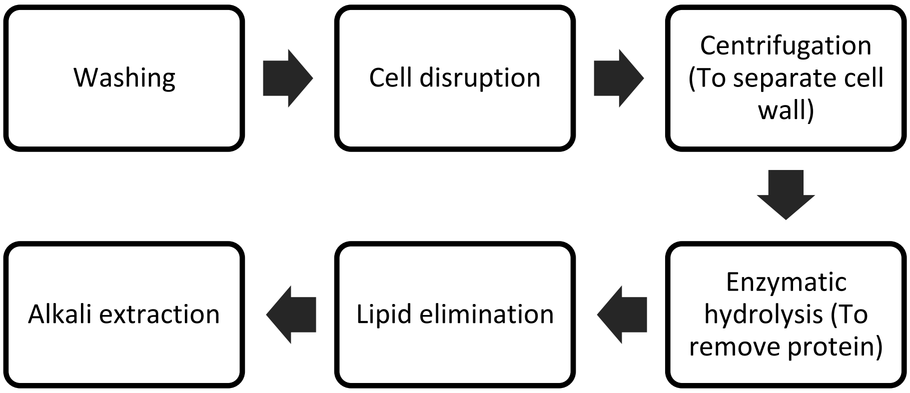
The cell wall can be broken using different methods. As described by EURaSYP (2023b), the yeast mass is placed in tanks at temperature of 45–55 °C, where the yeast growth stops and enzymes starts breaking down the macromolecules in the yeast while simultaneously disrupting the cell wall allowing the now smaller molecules to leave and mix in with the solution in the tank. Processing time and temperature significantly affect the taste of the final product.

The liquid is now centrifuged again to remove the yeast cell walls. Then, the yeast extract is concentrated in an evaporation process at approximately 60 ° C, after which the yeast extract is in the form of a liquid or a paste. If necessary for the intended use, the liquid yeast extract is dried using a spray dryer. (EURaSYP, 2023b)

3.3.3 Extracting high value components

When extracting high value components, the yeast cell wall must be broken. This can be done using physical, chemical or enzymatic methods. A great deal of the research concerning utilization of BSY is about extraction of β-glucans (Zeko-Pivač et al., 2023, p. 6). After the disruption of the cell wall, it is typical to use centrifugation to separate the cell wall from which the β-glucans are then extracted from (Wei et al., 2024, p.4). Figure 7 shows the main steps in extracting β-glucans from BSY.

Figure 7. The main steps in extraction of β-glucans. (Adapted from Wei et al., 2024, p. 4)



4 Practical test: Drying and preserving yeast

The practical test was carried out in the food processing premises at the Visamäki campus of Häme University of Applied Sciences. The goal was to study and observe the effects of drying and storage conditions on yeast viability in practice.

4.1 Background of practical test

Due to multiple reasons, the practical tests were performed using commercial brewer's yeast instead of actual brewer's spent yeast. The brewer's yeast used in the test is called Fermentis Safale US-05 (figure 8).

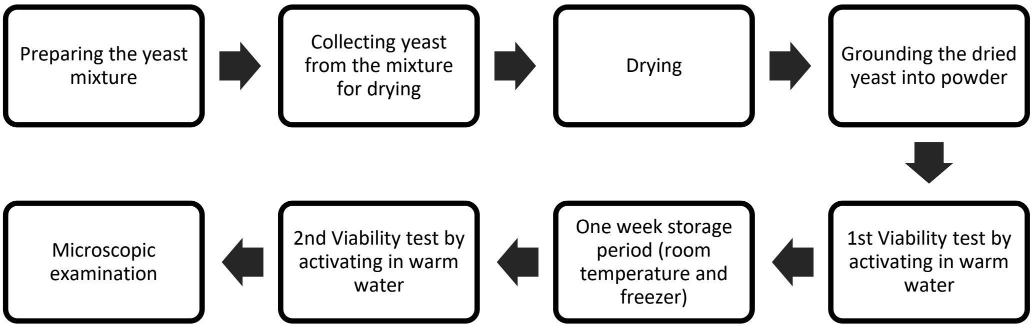
Figure 8. Fermentis Safale US-05 dry brewer's yeast (Melkkobrew, 2025).

Fermentis Safale US-05 is an American ale yeast suitable for production of neutral and well-balanced ales. The ideal fermentation temperature is between 18 and 26 °C and it forms a firm foam during fermentation. (Fermentis, 2025)

To simulate BSY to some extent, the yeast was mixed with brewing sugar and water and left at room temperature for two hours, so fermentation would begin. After a couple of hours, the mixture was moved into a fridge, so the yeast would rise on the surface. The yeast mass collected from the mixture was dried using three different methods. After drying, the yeast was ground into a powder in a mortar. The powdered yeast was divided into different samples for viability testing after drying and to be stored at room temperature and in the freezer for one week. After one week of storage time, viability testing was performed again.

Flow chart in figure 9 shows the execution and different steps of the practical test. More detailed description of the execution of and materials and methods used are given later.

Figure 9. Basic steps in the execution of practical test.



Yeast viability was tested by activating the yeast in warm water, approximately 30 °C in temperature. Approximately 0.5 grams of dried yeast was added into 10 milliliters of water. After 15 minutes, a sensory analysis was performed on the intensity of foaming and the color and smell of the yeast mixture. Viable yeast creates foam and bubbles, and the mixture appears milky in color with a recognizable scent of yeast. It is important to note, that this test is not an accurate way to determine yeast viability but can offer some indications about the condition of the yeast. Activation in warm water was chosen to be used in the test because it is simple and easy to perform, so it could be done even in the case that a microscope would not be available.

4.2 Materials, methods and execution

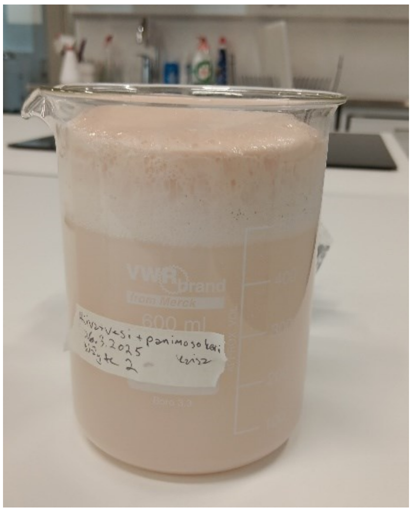
First, the yeast mixture was prepared using the following materials and equipment:

- Fermentis Safale US-05-yeast
- Brewing sugar (glucose)
- Water
- Beakers
- Glass rod for stirring
- Scale
- Thermometer

The oven drying was done twice. For the first time, yeast mixture was made by mixing 10 grams of yeast into 100 milliliters of warm water, temperature approximately 30 °C. 25

grams of brewing sugar was mixed with 400 milliliters of water. The yeast-water mixture was added to the brewing sugar-water mixture, stirred with a glass rod and left to stand at room temperature for two hours. The mixture was then moved into a refrigerator where it was stored overnight. This was done to make the yeast mass rise on the surface of the mixture. Figure 10 is of the yeast mixture before moving into a refrigerator.

Figure 10. Yeast mixture made of dried brewer's yeast, brewing sugar and water.



Next morning, the yeast mass was collected with a spoon into a coffee filter placed into a beaker. The liquid mixture was poured carefully into the sewer, and more yeast was collected from the mixture into the coffee filter.

The following equipment was used in drying the yeast mass harvested from the yeast mixture:

- Oven
- OBH Nordica Tasty Food Dehydrator 6775
- Drywinner 3 freeze dryer by Heto-Holten

Additionally, a scale was used to weigh the yeast before and after drying and evaporated moisture was calculated by using equation 1.

Equation 1. Evaporated moisture-%.

$$\frac{Weight_{wet} - Weight_{dry}}{Weight_{wet}} \times 100\ \%$$

The wet yeast mass was spread on a sheet of baking paper and put into the oven at temperature of 50 °C with air circulation on. The dried yeast was collected into a plastic cup and weighed on a scale. The second oven drying was carried out in the same way as the first except that a smaller amount of yeast mixture was prepared.

Yeast was dried in the food dehydrator twice and for the second drying, a smaller amount of yest mixture was prepared. The drying was carried out similarly to oven drying. The yeast mass collected from the yeast mixture was placed into a coffee filter and then spread on a baking paper cut to appropriate size and placed in the middle section of the food dehydrator to be dried. The dried yeast was collected into a plastic cup and weighed on a scale.

Freeze drying was carried out once. Yeast mixture was prepared and yeast mass collected as described earlier. Yeast mass was spread on a plastic dish suitable for the freeze dryer, weighed on a scale and placed in a freezer for 24 hours before drying. Dried yeast was collected into a plastic cup and weighed on a scale.

Results obtained from drying are presented in table 3 under chapter heading 5.1.1 Results from drying.

Next, the dried yeasts were ground into a powder in a mortar. The yeast powder was then divided into different samples for viability testing and to be stored at room temperature and in the freezer for one week.

The yeast viability was tested by activating the yeast in warm water after drying and after one week storage period. For this, the following materials and equipment were used:

- Dried yeast
- Water
- Measuring glass
- Falcon tube
- Thermometer
- Scale

Approximately 0.5 grams of dried yeast was mixed with 10 milliliters of approximately 30 °C water. The mixture was left to stand for 15 minutes, after which the formation of foam as well as the odor and general appearance of the mixture were assessed through sensory analysis.

After one week storage period, viability test by activation in warm water was carried out again. In addition, yeast cells were examined under a microscope to assess viability. The following materials and methods were used:

- Dried yeast
- Water
- Measuring glass
- Pipette
- Test tubes
- A microscope
- Sample slides and coverslips
- Methylene blue

The results from viability testing are presented under chapter heading 5.1.2 Results from viability testing.

5 Results

Based on literature and previous research data, proteins, amino acids and 5´-nucleotides and β-glucans appear to be the most valuable compounds for the food industry. The biological quality of BSY protein is high and since they originate from a side stream, BSY can be considered a good alternative source of protein (Marson et al., 2020, p. 11).

Yeast extracts made of BSY contain amino acids known as flavor enhancers, such as glutamic acid, aspartic acid, glycine and alanine (Zeko-Pivač et al., 2023, p. 7). Yeast extracts can be used to bring out meaty flavors in food products like soups, sauces and ready meals (EURaSYP, 2023a). Yeast extracts containing lots of 5´nucleotides create umami flavors and can also be utilized in the food industry (Zeko-Pivač et al., 2023, p. 8).

β-glucans can be used as thickeners and as water-retention or oil-binding agents and emulsion stabilizers. It is also possible to replace some of the fat in mayonnaise with yeast β-glucans. (Zeko-Pivač et al., 2023, p. 7) Whan added in dough, β-glucans from BSY increased fiber content and improved texture of bread (Jaeger et al., 2020, p.12).

5.1 Results from practical test

All results from practical tests are presented in this section. For clarity, results from drying and results from viability test are in separate sections.

5.1.1 Results from drying

Durations, weights of wet and dried yeasts and evaporated moisture calculated using equation 1 are presented in table 3.

Table 3. Results from drying.

	Duration (h)	**Weight of wet yeast (g)**	**Weight of dry yeast (g)**	$\frac{\boldsymbol{Weight_{wet}} - \boldsymbol{Weight_{dry}}}{\boldsymbol{Weight_{wet}}} \times \mathbf{100}\ \%$	**Evaporated moisture (%)**
Oven, 50 °C 1st drying	6	20.6	4.2	$\frac{20.6\ g - 4.2\ g}{20.6\ g} \times 100\ \% \approx$	79.6 %
Oven, 50 °C 2nd drying	5.5	19.0	3.8	$\frac{19.0\ g - 3.8\ g}{19.0\ g} \times 100\ \% \approx$	80.0 %
Food dehydrator 1st drying	4	22.7	3.3	$\frac{22.7\ g - 3.3\ g}{22.7\ g} \times 100\ \% \approx$	85.5 %
Food dehydrator 2nd drying	4.5	18.9	2.8	$\frac{18.9\ g - 2.8\ g}{18.9\ g} \times 100\ \% \approx$	84.9 %
Freeze drying	24 + 47.5 = 71.5	29.1	3.9	$\frac{29.1\ g - 3.9\ g}{29.1\ g} \times 100\ \% \approx$	86.6 %

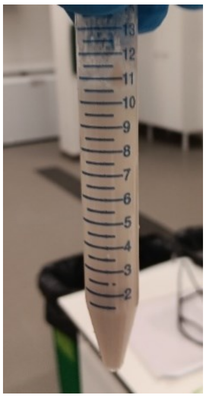
It is important to note that the results obtained from drying are not entirely accurate. Material losses occurred at almost all stages of drying, as the wet yeast mass got stuck on to tools and containers. Weighing was not done in the same way or on the same scale every time. In addition, the dried yeast contains brewing sugar from the yeast mixture since it was not removed before drying.

Freeze drying was the most effective method removing 86.6 % of moisture. It also had the longest duration of 71.5 hours, including 24 hours of pre-freezing and 47.5 hours of drying. Food dehydrator was the second most effective and the fastest method removing 85.5 % of moisture in 4 hours in the first and 84.9 % in 4.5 hours in the second drying. Oven drying was the least effective method. The first oven drying removed 79.6 % of moisture in 6 hours and the second removed 80.0 % in 5.5 hours. Both times the oven drying was cut short when the yeast darkened to prevent it from burning.

5.1.2 Results from viability testing and microscopy

Viability testing was conducted as described before. When testing oven-dried yeast, very mild foam formation with some bubbles could be observed, as well as a mild scent of yeast. The mixture had a milky color to it. The oven-dried, activated yeast is shown in figure 11.

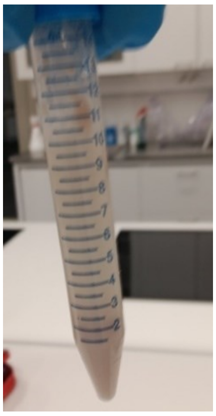
Figure 11. Oven-dried yeast when activated in warm water.



After one week of storage time at room temperature and in the freezer, the activation in warm water was performed again. The results were similar to the earlier ones. When examining the yeast sample with a microscope, it was observed that over half of the cells were dead, and the cells had clumped together.

When the yeast dried in food dehydrator was activated in warm water, some foam formation ang bubbling could be observed. The mixture had a mild odor of yeast and a milky, even color to it. Water-activated, food dehydrator-dried yeast is shown in figure 12.

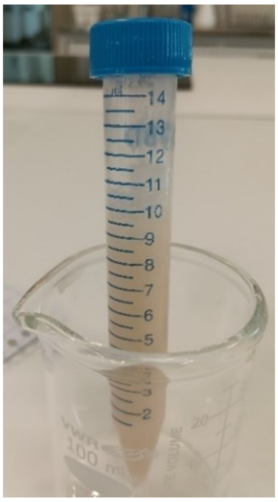
Figure 12. Food dehydrator-dried yeast when activated in warm water.



After a week, the results were similar. When examined by a microscope, it was observed that over half of the cells were dead, and the cells were clumped together.

When freeze-dried yeast was activated in warm water, mild foam formation could be observed with some bubbles. The mixture was milky in color and had a very distinct scent of brewing sugar. Only very mild scent of yeast could be sensed. Water activation of freeze-dried yeast is shown in figure 13.

Figure 13. Freeze-dried yeast activated in warm water.



When activation in warm water was performed after one week, the results were similar. When examined with a microscope, it was observed that most of the cells were dead. Unlike in oven-dried and food dehydrator-dried yeast samples, cells were not clumped together.

5.2 Summary and discussion of practical test results

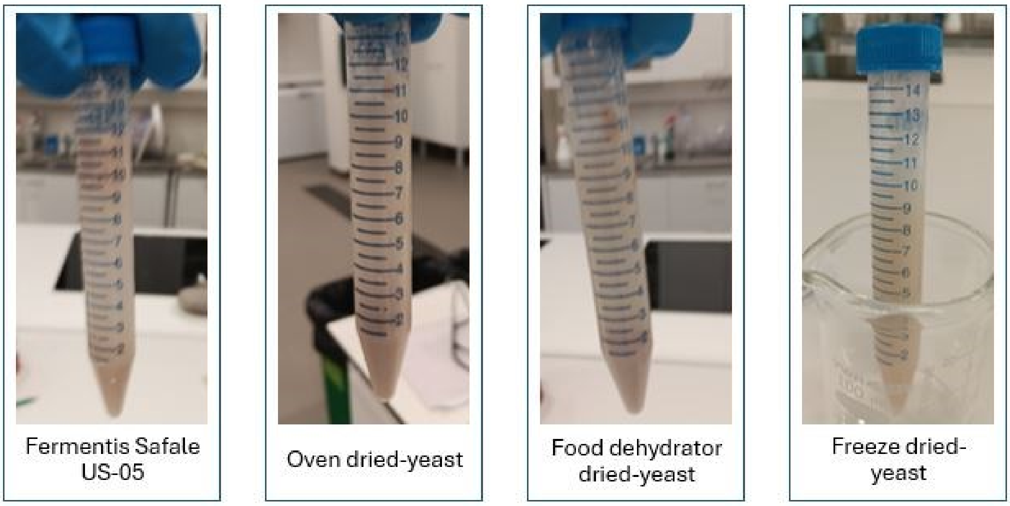
In appearance, the food dehydrator-dried yeast resembled Fermentis Safale US-05 the most. Ground oven-dried yeast was very coarse and was darker in color. Freeze-dried yeast was light in color and when ground, it made into a very fine powder. This made it difficult to process when testing viability. Figure 14 shows the dried and ground yeast samples and Fermentis Safale US-05 yeast.

Figure 14. Fermentis Safale US-05 yeast next to the dried and ground yeast samples.

Fermentis Safale US-05 | Oven-dried yeast | Food dehydrator-dried yeast | Freeze-dried yeast

For comparison, the viability test and microscopic examination were also done with commercial brewer’s yeast. When activated in warm water, commercial brewer’s yeast formed significantly more bubbles and foam than the dried yeasts (figure 15). Additionally, when sample of commercial brewer’s yeast was examined under a microscope, the number of living cells was noticeably higher than the number of dead cells.

Figure 15. Commercial brewer's yeast (Fermentis Safale US-05) and dried yeast samples activated in warm water.



Fermentis Safale US-05 | Oven dried-yeast | Food dehydrator dried-yeast | Freeze dried-yeast

Different storage conditions had no notable effects on the dried yeasts, which was partially to be expected due to the very short storage period. Since all dried yeasts still contained some moisture and were not packed airtight, it is most likely that they would have started to spoil before long. Properly dried and packaged yeast can be stored at room temperature.

The observations in microscopic examination were consistent with the results from viability testing. Both activation in warm water and microscopic examination suggested that the yeast dried in the food dehydrator had best maintained its viability. This may be explained by a lower drying temperature and steady and efficient air circulation. In the oven, the temperature is probably not the same at every part and therefore the yeast did not dry evenly. A more accurate assessment of yeast viability could have been obtained using a cell counting chamber in the microscopic examination.

6 Conclusions

BSY has many potential applications in the food industry. However, more research is needed to solve the issues with lowering the content of nucleic acids to remove the negative health effects and to find the ideal processing methods for production of BSY products.

Based on the results of the practical test, it can be concluded that if not done correctly drying can damage yeast viability significantly. Before the actual drying, it is recommended to remove as much moisture from the yeast mass as possible by using a centrifuge or other suitable method. Also, the yeast should be clean from any residues from the brewing process, since it was observed that the freeze-dried yeast had a very distinct smell of brewing sugar and same phenomenon might occur again. Overall, it is advisable to wash BSY before usage in food production.

Drying is a good method of preservation, as it reduces the cost of storing and transporting BSY. The correct drying method should be chosen based on the intended use since, for example, maintaining yeast viability is not necessary in all applications. In addition, correct and controllable process conditions during drying are important while drying yeast.

7 Discussion

When planning possible utilization of BSY, it is important to thoroughly find out as much information as possible about the conditions of the fermentation process, the yeast stock used, the number of re-pitchings, which state of fermentation the yeast was cropped and so on. All these factors affect the properties of BSY and thus also its potential for further utilization.

Efficient utilization of side streams promotes sustainable development. Comprehensive utilization of raw materials provides a way for companies to reduce their environmental impact and waste management costs while increasing economic profitability. To maintain the sustainability of the operations, various factors must be considered, and their environmental impact must be taken into account. This could mean, for example, evaluating the impact of chemicals used in processing or transportation of materials.

The thesis process was challenging and rewarding at the same time. Although it was unfortunate that actual BSY could not be obtained for the test according to the original plan, the changing situations were beneficial. The need to discover alternative plans and test setups strengthened my pressure tolerance and ability to find new perspectives and ideas, and those are certainly useful skills for work and life in general.

References

AngelYeast Co., Ltd. (n.d.). *Frequent questions* [figure]. https://en.angelyeast.com/about-us/frequent-questions.html

Carry Brewtech. (n.d*.). 2000L Beer Fermentation Tank* [figure]. Shandong Carry Equipment Company Co., Ltd. Retrieved Apr 16, 2025, from https://www.carrybrew.com/2000l-beer-fermentation-tank.html

Enari, T-M. & Mäkinen, V. (2014). *Panimotekniikka*. The 3rd edition. Panimolaboratorio.

European Association for Specialty Yeast Products (EURaSYP). (2023a). *What is yeast extract?* https://www.yeastextract.info/about-yeast-extract/what-is-yeast-extract/

European Association for Specialty Yeast Products (EURaSYP). (2023b). *How is yeast extract produced?* https://www.yeastextract.info/about-yeast-extract/how-yeast-extract-is-produced/

European Parliament (2023, May 24). *Circular economy: definition, importance and benefits.* https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits

Fermentis. (2025). *SafAle^{TM}US-05.* Retrieved May 8, 2025, from https://fermentis.com/en/product/safale-us%e2%80%9105/

Ferreira, I. M. P. L. V. O., Pinho, O., Vieira, E., & Tavarela, J. G. (2010). Brewer's Saccharomyces yeast biomass: characteristics and potential applications. *Trends in food science & technology, 21*(2), 77–84. https://doi.org/10.1016/j.tifs.2009.10.008

Goldammer, T. (2022). *The Brewer's Handbook. The Complete Book to Brewing Beer.* The 3rd edition. Apex Publishers.

Häme University of Applied Sciences (HAMK). (n.d.). *HÄMILIS Waste to a Minimum, Added Value to the Maximum.* Retrieved Apr 15, 2025, from https://www.hamk.fi/en/projects/hamilis/

Jaeger, A., Arendt, E. K., Zannini, E., & Sahin, A. W. (2020). Brewer's spent yeast (BSY), an underutilized brewing by-product. *Fermentation, 6*(4), 123. https://doi.org/10.3390/fermentation6040123

Łukaszewicz, M., Leszczyński, P., Jabłoński, S. J., & Kawa-Rygielska, J. (2024). Potential Applications of Yeast Biomass Derived from Small-Scale Breweries. *Applied Sciences 14*(6). https://doi.org/10.3390/app14062529

Marson, G. V., de Castro, R. J. S., Belleville, M. P., & Hubinger, M. D. (2020). Spent brewer's yeast as a source of high added value molecules: A systematic review on its characteristics, processing and potential applications. *World Journal of Microbiology and Biotechnology, 36*(7). https://doi.org/10.1007/s11274-020-02866-7

Mathias, T. R. D. S., Alexandre, V. M. F., Cammarota, M. C., de Mello, P. P. M., & Sérvulo, E. F. C. (2015). Characterization and determination of brewer's solid wastes composition. *Journal of the Institute of Brewing*, *121*(3), 400-404. https://doi.org/10.1002/jib.229

Melkkobrew. (2025). *Safale US-05 11,5g oluthiiva* [figure]. Viinitalo Melkko Oy. Retrieved Apr 16, 2025, from https://www.melkkobrew.fi/oluthiiva-safale-us-0556-115-gr

Natural Resources Institute Finland (Luke). (n.d.). *Examples of value chains*. https://www.luke.fi/en/luonnonvaratieto/science-and-information/biomass-atlas/examples-of-value-chains

Pacheco, M. T. B., Caballero-Cordoba, G. M., & Sgarbieri, V. C. (1997). Composition and nutritive value of yeast biomass and yeast protein concentrates. *Journal of nutritional science and vitaminology, 43*(6), 601-612. https://www.jstage.jst.go.jp/article/jnsv1973/43/6/43_6_601/_pdf

Quain, D. & Boulton, C. (2001). *Brewing Yeast and Fermentation.* John Wiley & Sons, Incorporated.

Saarela, A-M. (2010). Säilöntämenetelmiä. In A-M. Saarela (ed.), P. Hyvönen (ed.), S. Määttälä (ed.) & A. von Wright (ed.), *Elintarvikeprosessit* (pp. 279–313). The 3rd revised edition. Savonia-ammattikorkeakoulu.

Schreuder, M. P., Mooren, A. T., Toschka, H. Y., Verrips, C. T., & Klis, F. M. (1996). Immobilizing proteins on the surface of yeast cells. *Trends in biotechnology, 14*(4), 115–120. https://www.academia.edu/download/46921212/0167-7799_2896_2910017-220160630-31975-141yn46.pdf

Sinebrychoff. (n.d.-a). *Oluen valmistus Sinebrychoffilla.* https://sinebrychoff.fi/olut/oluen-valmistus-sinebrychoffilla/

Sinebrychoff. (n.d.-b). *Tiesitkö? Olutostoksestasi ilahtuu lehmäkin – mäski maittaa monille.* https://sinebrychoff.fi/vastuu/tekojamme/oluenvalmistuksesta-ei-jaeae-jaetettae/

United Nations Development Programme. (n.d.). *Sustainable Development Goals.* https://www.undp.org/sustainable-development-goals

Walker, G. (1998). *Yeast Physiology and Biotechnology.* John Wiley & Sons Ltd

Wei, G., Shang, W., Xie, Z., Zhang, M., Dan, M. Zhao, G., Wang, D. (2024). Unlocking High-Value Components from Brewer's Spent Yeast for Innovative Food Applications. *Food Bioscience (59).* https://doi.org/10.1016/j.fbio.2024.104047

Zeko-Pivač, A., Habschied, K., Kulisic, B., Barkow, I. & Tišma, M. (2023). Valorization of Spent Brewer's Yeast for the Production of High-Value Products, Materials, and Biofuels and Environmental Application. *Fermentation 9*(3). https://doi.org/10.3390/fermentation9030208

Appendix 1. Thesis Data Management Plan

HAMK
Hämeen ammatti-
korkeakoulu

Thesis Data Management Plan

Thesis title: Brewery Side Stream Yeast -Utilization and Processing for Food Industry Applications

Thesis author: Kaisa Levänen

1 Description of thesis research data

Thesis research data consists of results obtained from the practical test. The results include numeric and verbal representations of the results and photographs taken during the practical test. Additionally, literature, previous research data and other information are used in this thesis work. The data gathered from these sources includes text files and images, and the origin, authors, and data sources are mentioned according to HAMK's citation guidelines.

2 Management and storage of the research data

The data will be stored and processed on the thesis author's own password-protected computer. Backups of the data will be saved in USB flash drive. The data does not contain confidential or personal information and therefore can be accessed by other parties if necessary.

3 Processing of personal data and sensitive data

No personal data is collected in the thesis research.

4 Ownership of research data

The thesis worker owns the research data obtained from the practical test.

5 Further use of research data after the completion of the thesis

The research data will not be reused. The thesis author will securely store the data for one year from the date of thesis approval to ensure the results can be verified if necessary, and then securely destroy the data.