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ORIGINAL PAPER

Anhydrobiosis in yeast: effect of selenium on the resistance of yeast cells in the dehydration-rehydration process*

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Abstract

Recent biotechnological research has contributed significantly to the continuous expansion and understanding of the mechanisms of eukaryotic cell functioning in yeast. Nevertheless, the influence of selenium on the resistance of yeast cells and the processes of anhydrobiosis requires extending the existing knowledge. Anhydrobiosis is a mechanism enabling microorganisms like yeast to survive extreme desiccation conditions by temporarily suspending metabolism. Introducing selenium as a factor influencing anhydrobiosis directs attention to cellular interactions and the adjustment of metabolic and defence processes in yeasts under extreme conditions. The *Rhodotorula glutinis* CCY 20-2-26 yeast exhibited the highest survival rate after 48 h of cultivation and slow rehydration, with selenium concentrations ranging from 0.5 to 5 mg Se L^{-1} showing no significant difference from the control, while concentrations of 10-20 mg L^{-1} resulted in a statistically significant decrease in cell survival to around 60% from the control's 70%. Similarly, the *Saccharomyces cerevisiae* ATCC 7090 yeast, after undergoing slow rehydration and 48 h of cultivation, demonstrated the highest and stabilized survival rate at 60%, with no significant differences observed in survival compared to the control across tested selenium concentrations. This knowledge not only advances our understanding of microbial adaptation but also has potential applications in biotechnology for long-term storage and production of highly active yeasts

Keywords: selenium; yeast; anhydrobiosis, dehydration – rehydration

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INTRODUCTION

Anhydrobiosis, also known as desiccation tolerance, represents an area of research enabling microorganisms, such as yeasts, to survive under extreme desiccation conditions. Throughout evolution, microorganisms have developed survival mechanisms in response to extreme conditions, such as very low temperatures in winter and periodic droughts in summer (Kurylenko et al. 2019). These survival mechanisms lead to a temporary, reversible suspension of metabolism, which is a crucial adaptation to challenging environmental conditions. This state is known as anabiosis or cryptobiosis.

Yeasts, as microorganisms, also undergo anhydrobiotic processes in response to dehydration, which is associated with the temporary suspension of metabolism. Recent studies (Rapoport 2017) on anhydrobiosis in yeast cells utilize the latest molecular technologies and genetic analyses, enabling a comprehensive understanding of the molecular processes occurring at the cellular level during this state (Kulikova-Borovikova et al. 2018).

Under severe freezing conditions, cells may enter a state of cryobiosis, while under dry conditions, they may enter anhydrobiosis. Anhydrobiosis was discovered in 1701 by the Dutch naturalist Anthony van Leeuwenhoek (Rapoport et al. 2019). Initially associated with survival in natural conditions, the state of anhydrobiosis has found applications in various industrial fields. Despite earlier studies on anhydrobiosis, detailed physiological and biochemical research began only in the second half of the 20th century, when appropriate methodological approaches became available.

Selenium can be classified as an essential mineral component of all living organisms (Zhao et al. 2024). The most significant biological significance of selenium in the body is associated with its occurrence in the active centers of many enzymes and proteins (in the form of selenocysteine) (Genchi et al. 2023). Selenium is an element with critical physiological functions (Minich 2022). This element is involved in the metabolism of hydrogen peroxide and lipid hydroperoxides. It is an integral part of some enzymes, including glutathione peroxidase (GPx), and thioredoxin reductase (TRxR) – Brigelius-Flohé, Flohé (2017), which protect cells from the harmful effects of free radicals generated during oxidation processes (Zoidis et al. 2018). Thanks to the ability to permanently incorporate macroelements and trace elements into cellular structures, yeast has become a source of protein and deficit elements, including selenium (Du et al. 2024).

Introducing selenium as a factor activating oxidative stress can significantly influence the process of anhydrobiosis by activating relevant signalling pathways and adaptive mechanisms (Cornette et al. 2023). This, in turn, directs attention to the interactions occurring during anhydrobiosis, illustrating how yeasts adjust their metabolic and defence processes to extreme envi-

ronmental conditions (appropriate selenium doses). Oxidative stress caused by selenium can induce the expression of genes related to cellular defence (genes encoding thioredoxin, glutathione peroxidase) – Cornette, Kikawada (2011). As a result, yeasts may activate adaptive mechanisms that enable better survival under anhydrobiotic conditions. Additionally, selenium supplementation may affect metabolic processes in yeast cells. Selenium may be involved in regulating the activity of enzymes associated with redox reaction metabolism, which can impact the energetic processes occurring in cells during anhydrobiosis.

This article focuses on an analysis of the mechanisms of anhydrobiosis in yeast cells, with particular emphasis on the influence of selenium. These discoveries not only enrich the knowledge about the fundamental adaptive processes of microorganisms to extreme conditions, but also have potential implications in the field of biotechnology, where anhydrobiosis may be used for long-term storage and production of highly metabolically active yeasts.

MATERIALS AND METHODS

Two strains of yeast, *Saccharomyces cerevisiae* ATCC 7090 and *Rhodotorula glutinis* CCY 20-2-26, were used in this study. The strains were obtained from the American Type Culture Collection (ATCC) and the Culture Collection of Yeasts (CCY, Slovakia), respectively.

Yeast inoculum was prepared by inoculating a 24-h yeast strain culture from a Petri dish into 100 mL of liquid YPD medium. To determine the degree of anhydrobiosis in the yeast, the experimental YPD medium (glucose 20 g L^{-1}, peptone 20 g L^{-1}, yeast extract 10 g L^{-1}) was used with the addition of an aqueous solution of sodium selenite (IV) and the pH adjusted to 4.8. The selenium water solution was prepared by dissolving 0.219 g of Na_2SeO_3 in 100 mL of deionized water, resulting in a final concentration of Se^{4+} ions of 1000 mg L^{-1}. The YPD medium and the aqueous solution of Na_2SeO_3 were sterilized separately at 121°C for 15 min. The sterile selenium solution was added to the sterile YPD medium in volumes to achieve final selenium concentrations in the experimental medium ranging from 0 to 20 mg Se^{4+} L^{-1}. The final step involved adding yeast inoculum (10% v/v). Cultures were conducted for 48 h on a shaker (SM-30 Control E. Büchler, Germany) with the rotary motion at 150 rpm and at a temp. of 28°C.

The biomass yields of *S. cerevisiae* ATCC 7090 and *Rhodotorula glutinis* CCY 20-2-26 yeasts cultivated in media with varying selenium concentrations (0-20 mg Se L^{-1}) were determined by drying to a constant weight at 105°C. Thirty millilitres of post-culture liquid was sampled from the yeast cultures and put into pre-weighed flasks. After centrifugation, the supernatant was decanted, and the remaining biomass at the bottom was dried

(Zelmed SLM 32 dryer) until reaching a constant weight value (approximately 24 h). Taking the flask's empty weight into account, the biomass yield was calculated per L of culture and expressed in grams of dry substance.

The biomass harvested after 24- and 48-h of cultivation was centrifuged at 5000 rpm for 15 min (Centrifuge MPW-340). Additionally, the centrifuged biomass was drained on Whatman filter paper (diameter 45 mm, porosity 0.45 μm) and compressed through a metal sieve with the pore diameter of 1 mm. Dehydration of the biomass was conducted by convection in an oven set at 37°C, which lasted for 15 h, according to the method developed by Rapoport and Meysel (1985). The residual moisture content under these conditions was approximately 10%. At this residual moisture, yeasts can maintain their viability through the process of anhydrobiosis (Borovikova et al. 2014; Kulikova-Borovikova et al. 2018).

The yeast biomass was rehydrated in Falcon tubes containing sterile distilled water. Two rehydration methods were employed: rapid and slow. Rapid rehydration: the dehydrated biomass was rehydrated in distilled water (5 mL) for 10 min with simultaneous agitation (back-and-forth rocking motion, 80 rpm). After centrifugation of the biomass, 3500 rpm, 10 min (Centrifuge MPW-340, Warsaw, Poland), the supernatant was decanted, and then distilled water was added again, transferring the quantitative suspension of biomass to pre-weighed weigh vessels. The biomass was dried at 105°C for 15 h (Borovikova et al. 2014, Kulikova-Borovikova et al. 2018). Slow rehydratation: the dehydrated biomass was rehydrated in a steam chamber at 37°C for 2 h. After gradual rehydration with steam, the biomass was suspended in distilled water and transferred quantitatively to pre-weighed weigh vessels. The biomass was dried at 105°C for 15 h (Borovikova et al. 2014, Kulikova-Borovikova et al. 2018).

The viability of the dehydrated cultures was determined by fluorescence microscopy (Olympus DP71, Riga, Latvia) using primuline dye (Sigma Aldrich, 206865) – Dauss et al. (2021). Under primuline dye and UV light, yeasts that did not survive the dehydration process exhibited bright green colour in a microscopic image, while live cells remained colourless. Viability was calculated by determining the ratio of all cells to dead cells.

The results were subjected to analysis of variance using Statgraphics Plus 5.1 software. The Tukey's test was employed to assess the significance of differences between the means in the individual groups at a significance level of $\alpha = 0.05$. Prior to analysis, normality of data distribution was verified using the Shapiro-Wilk test.

RESULTS AND DISCUSSION

Selenium is known for its antioxidant properties and role in oxidative metabolism. Moreover, depending on the dose, this element can interact with

various metabolic processes supporting cell protection against stress, e.g. osmosis. The experiments allowed us to assess the variability of yeast resistance depending on the supplemented dose of selenium. According to Trofimova et al. (2010), determining yeast cell viability using primuline is an appropriate method for studying yeast dehydration. This method has been used since it was developed by Rapoport and Meysel (1985), and continues to be effective, hence its employment in the current study. Figure 1 shows

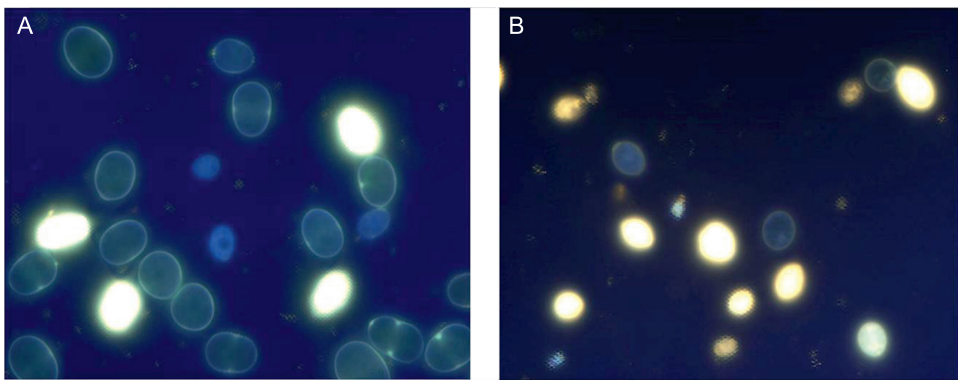

Fig. 1. Fluorescence microscope images of *Rhodotorula glutinis* CCY 20-2-26 (A) and *Saccharomyces cerevisiae* ATCC 7090 (B) yeast cells

representative images from a fluorescence microscope corresponding to *R. glutinis* CCY 20-2-26 yeast cells (1A) and *S. cerevisiae* ATCC 7090 (1B) cultivated in media with the addition of selenium in an amount of 2 mg L^{-1} for 48 h. Viability expressed as a percentage was calculated based on the ratio of live cells to all cells visible in the microscopic images, where bright yellow-green cells were considered dead. Two yeast rehydration methods were applied: rapid (10 min) and slow (60 min) rehydration. Figures 2A and 3A present the results of cell viability for *Rhodotorula glutinis* CCY 20-2-26 and *S. cerevisiae* ATCC 7090, respectively. The yeast cells were subjected to examination after 24 and 48 h of cultivation.

In the case of rapid rehydration of the *R. glutinis* CCY 20-2-26 yeast strain (Figure 2A), the selenium content had no effect on the cell viability of this microorganism after 24 h of cultivation (viability remained at 30%). During the subsequent day of cultivation, an increase in cell viability was observed compared to the results observed the previous day, reaching 62%. *R. glutinis* yeast cells cultivated in media with selenium showed lower viability compared to the control group, and statistically significantly lower viability (38%) was obtained in media with the highest tested selenium dose of 20 mg L^{-1}. It is worth noting the viability results of the tested representative of red yeasts, *R. glutinis* CCY 20-2-26, after the slow rehydration process. After the first day of cultivation, the viability results were already similar to those obtained after 48 h of cultivation in the case of rapid rehydration. The viability of yeast cells (slow rehydration) in media with

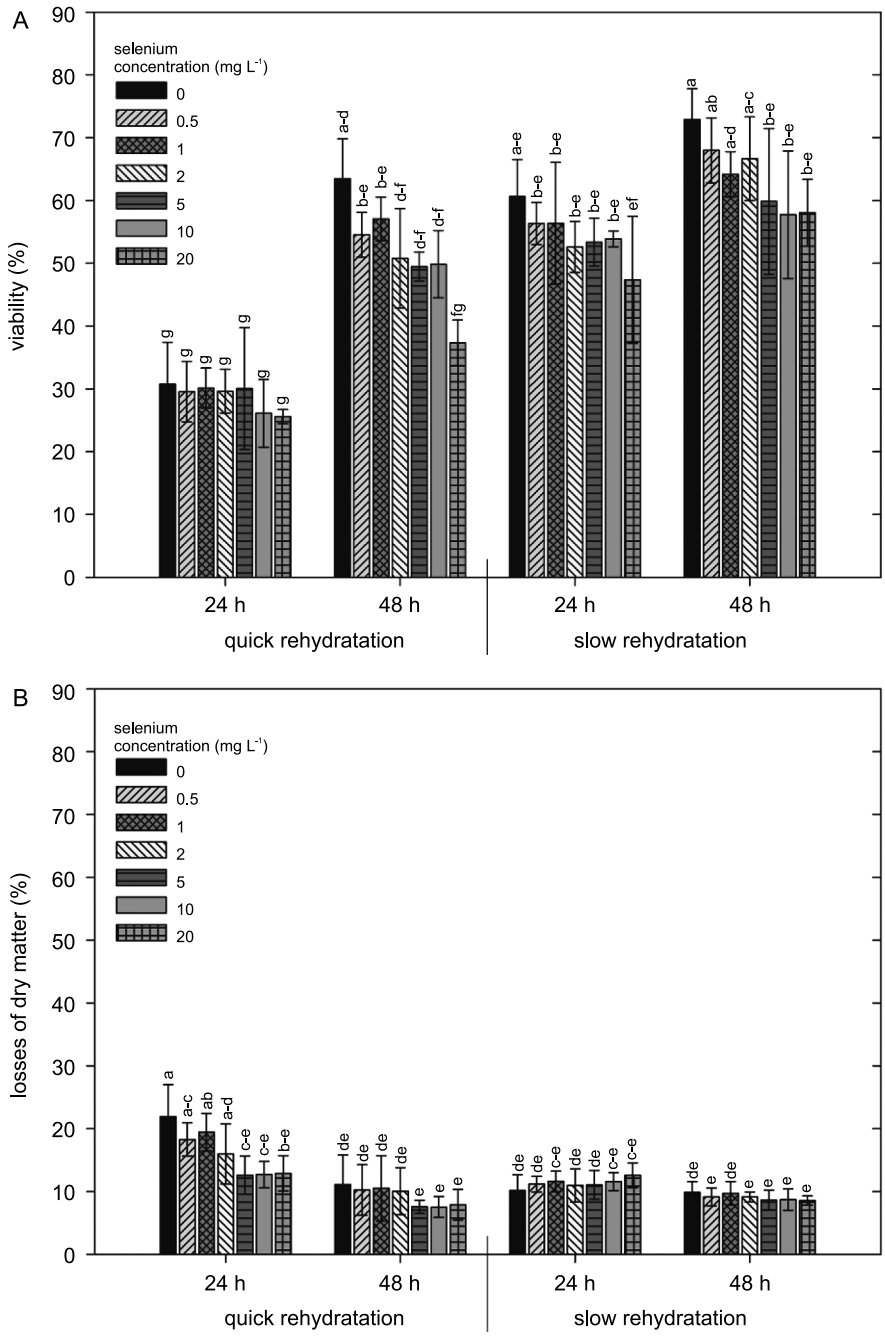

Fig. 2. The influence of selenium on the viability (A) and cell membrane permeability (losses) (B) of *Rhodotorula glutinis* (CCY 20-2-26) cells after the dehydration-rehydration process. Means with the same letter did not differ significantly

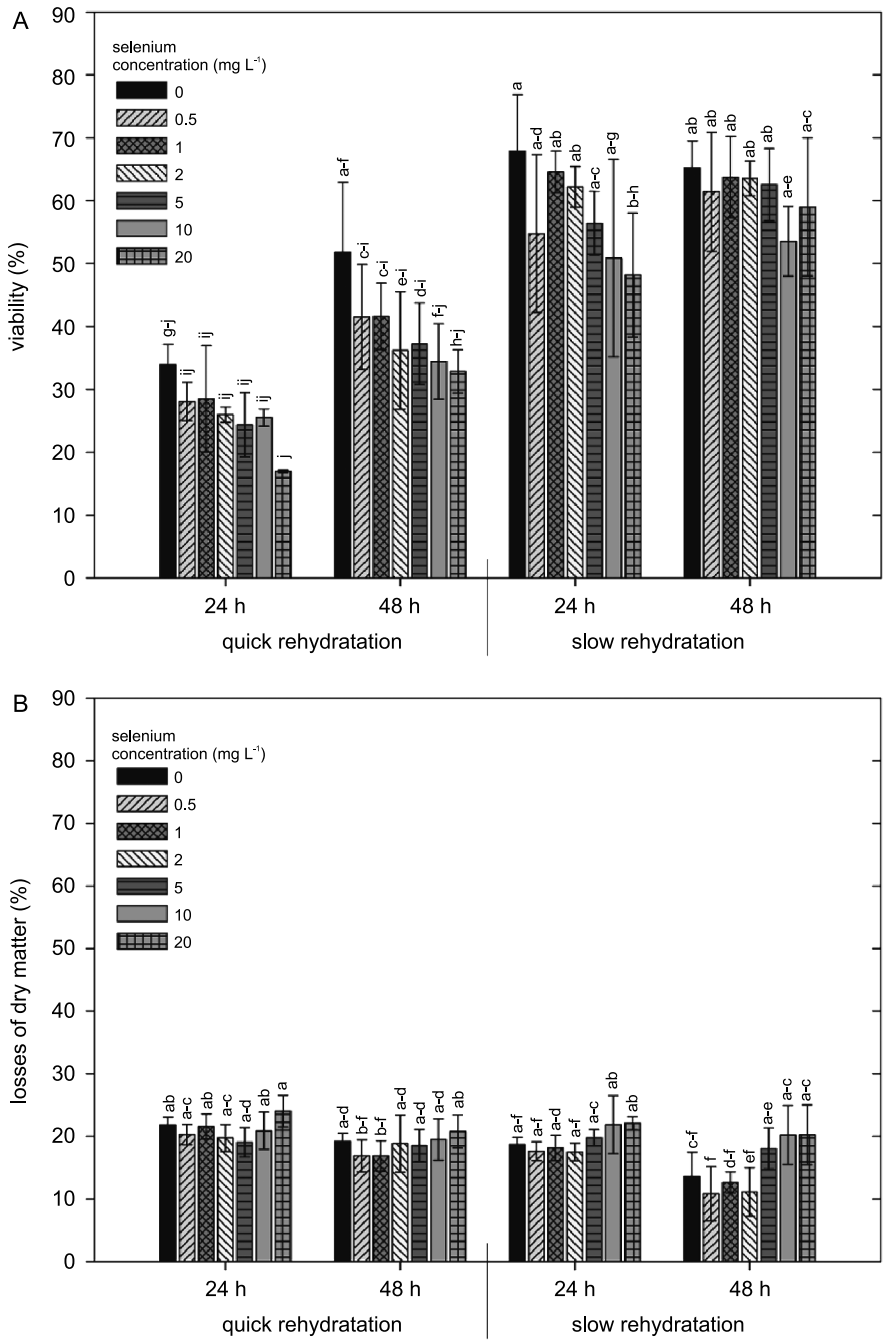

Fig. 3. The influence of selenium on the viability (A) and cell membrane permeability (losses) (B) of *Saccharomyces cerevisiae* (ATCC 7090) cells after the dehydration-rehydration process. Means with the same letter did not differ significantly

the addition of selenium was significantly lower compared to the control after 48 h only for the cultivation with selenium doses of 10 and 20 mg L^{-1}. The highest viability results were obtained on the second day of cultivation for cells subjected to the slow rehydration process.

The rapid rehydration process had a similar effect on *S. cerevisiae* as observed for *R. glutinis* CCY 20-2-26 yeast. After 24 h, the viability of *S. cerevisiae* ATCC 7090 yeast was low (18.5-34%), with even the highest selenium dose of 20 mg L^{-1} not being statistically significant compared to the control group. The viability results of *S. cerevisiae* yeast after the second day of cultivation were slightly higher compared to the results from the first day.

The slow rehydration process resulted in a significant increase in the viability of *S. cerevisiae* ATCC 7090 cells after 24 h of cultivation, compared to the results obtained for cells subjected to the rapid rehydration process, also after 24 h. For the first day of cultivation, no decrease in viability was observed for yeast cultivated in the presence of selenium compared to the control (slow rehydration), except for the highest tested dose – 20 mg L^{-1}. Extending cultivation of the *S. cerevisiae* ATCC 7090 strain to 48 h did not significantly improve the viability results. Additionally, no statistically significant differences were observed between results after 24 and 48 h of experimental cultivation supplemented with selenium. Selenium doses ranging from 0.5 to 20 mg L^{-1} had a similar effect on yeast cell viability.

One of the main factors determining the resistance of yeast cells to dehydration and subsequent rehydration is maintenance of the structural integrity of the cell membrane (Rapoport et al. 1995, Trofimova et al. 2010). In the present study, we attempted to investigate the integrity of yeast cell membranes in response to the presence of different doses of selenium in the culture media, and the results for both tested strains are presented in Figures 2B and 3B as cellular losses (%). Similar to the viability test, the results for cells subjected to rapid and slow rehydration processes are presented.

The highest cellular losses of *R. glutinis* CCY 20-2-26 yeast were noted after rapid rehydration and cultivation for 24 h. The presence of selenium at levels of 5-20 mg L^{-1} improved the integrity of the cell membrane and significantly reduced cellular losses. After the second day of cultivation, no significant changes in cellular losses (8-10%) were observed. Conducting the slow rehydration process did not improve the results of cellular losses (9-10%) after either 24 or 48 h of cultivation.

For the *S. cerevisiae* ATCC 7090 strain, yeast cells after rapid rehydration were characterized by losses at a level of 20% in both the control and experimental (in the presence of selenium) groups. On the second day of cultivation, the condition of the cell membrane of yeast cells subjected to rapid rehydration did not improve, hence the losses remained similar. Conducting slow rehydration and cultivation for 48 h with a selenium concentration in the medium ranging from 0.5 to 2 mg L^{-1} resulted in lower

values of cellular losses (11-12%), while cellular losses in the control group were 14%.

The topic of yeast cell anhydrobiosis is rarely encountered in the literature, with most available studies dating back over 30 years (Sęk et al. 2023). To date, no one has provided results regarding the influence of selenium ions and the process of anhydrobiosis on the physiological activity of yeast cells. However, research on the impact of other metal ions (sodium, potassium, calcium, magnesium) (Khroustalyova et al. 2001, Trofimova et al. 2010, Borovikova et al. 2014) on anhydrobiosis is available, which will be referred to in the discussion of the results presented above.

According to Trofimova et al. (2010), yeast cell death following dehydration and rehydration processes is a result of damage to the cell membrane, specifically the phase transitions of phospholipids in the membrane. Dehydration of yeast cells leads to an increase in the temperature of membrane phospholipids, resulting in a transition of the phase state from gel to liquid-crystalline. A transient increase in the permeability of the phospholipid bilayers leads to increased permeability of the cell membranes, which may result in leakage of intracellular substances and ultimately lead to cell death (Rapoport et al. 2009).

Trofimova et al. (2010) research confirmed the positive effect of magnesium and calcium ions on the resistance of *S. cerevisiae* yeast cells to dehydration and rehydration lasting 60 min. The metals studied played a crucial role in maintaining the stability of the cell membranes of these microorganisms. Calcium ions increase the resistance of yeast cells to dehydration, especially in cultures susceptible to the stress associated with exponential growth (Khroustalyova et al. 2001). A magnesium concentration of 150 mg L^{-1} in the medium resulted in an increase in the survival rate of yeast cells in the stationary growth phase to 55% compared to the control group, where it was only 25%. A calcium ion content at concentrations of 2 and 5 g L^{-1} allowed survival rates of 70% and 75%, respectively, to be achieved.

The strain of *S. cerevisiae* ATCC 7090 studied here, after a slow rehydration process lasting 60 min following 48 h of cultivation, exhibited a survival rate in the control group of 65%, and the addition of selenium had a slight effect on cell viability. The *R. glutinis* CCY 20-2-26 strain after 48 h of cultivation and slow rehydration showed a survival rate of 70% in the control group, while selenium concentrations of 10 and 20 mg L^{-1} resulted in a significant decrease in viability to 57%.

In another study, Kurylenko et al. (2019) investigated the process of anhydrobiosis in *Ogataea (Hansenula) polymorpha* yeast cells. The research confirms the positive impact of slow rehydration on the cells of the studied yeast. An increase in the survival rate of the tested strain was observed to reach from 37% (for rapid rehydration) to 82% (for slow rehydration). It is worth noting that after 6 months of storage, the strain exhibited reduced survival rates of 32% and 64% for rapid and slow rehydration,

respectively. The results of Kurylenko et al. (2019) are consistent with those obtained for our studied yeast strains *R. glutinis* and *S. cerevisiae*, where the positive effect of a prolonged slow rehydration process was also observed, allowing for cell survival at a high level of 60-70%, despite the presence of selenium ions.

Rapoport et al. (2014) reported that the viability of *S. cerevisiae* yeast cells dehydrated during the exponential growth phase was very low, around 15%. The same cells from the stationary growth phase exhibited a survival rate of 60%, and the slow rehydration process increased viability to 80%. Slow rehydration serves to mitigate the membrane damage resulting from reconstitution of the necessary amount of bound water.

The response to dehydration of osmotolerant yeast *Debaryomyces hansenii* J26 was studied by Latvian scientists (Khroustalyova et al. 2001). Cultivation was carried out in YPD medium as a control experiment and in the same medium supplemented with 10% NaCl (as an experimental test). The yeast culture of *S. cerevisiae* 14 served as an additional reference point. The survival results of *D. hansenii* yeast on the first day of cultivation in the control medium ranged from 56-84% and decreased to 53-67% on the second day of cultivation in the stationary phase. When a 10% NaCl supplement was added to the YPD medium, the survival rates improved to 77-88% on the first day of cultivation and 88-90% on the second day. The model yeast strain *S. cerevisiae* 14 exhibited much lower survival rates on the first day of cultivation, ranging from 17-31%. Survival rates in the stationary phase were at the level of 70-78%, which was higher than that for *D. hansenii* J26. The survival results after the rapid rehydration process for the yeast strains *S. cerevisiae* ATCC 7090 and *R. glutinis* CCY 20-2-26 investigated in the present study are comparable to the results obtained by Khroustalyova et al. (2001). The results obtained for the *D. hansenii* J26 strain turned out to be very interesting because they exhibited high cell viability in the control medium. Additionally, the research showed that growth under high salinity improves dehydration tolerance.

Unfortunately, it is not always possible to improve the viability of yeast cells after dehydration by employing slow rehydration, which assists in restoring the normal organization of the cell membrane structure. In the same study by Rapoport et al. (2014), *S. cerevisiae* 14 yeast cells cultured at 37°C, in both the exponential and stationary growth phases, exhibited high sensitivity to dehydration, with a survival rate of only 5%. Conducting slow rehydration did not enhance the viability of the tested microorganisms.

The highest cell survival among the *Saccharomyces* species was achieved by Rapoport et al. (2014). The strain studied was the thermotolerant *S. cerevisiae* TS1, which, after dehydration and rapid rehydration in the stationary growth phase, exhibited a survival rate of 80%. Gradual slow rehydration of this strain maintained cell viability at a record level of 90-95%, close to the maximum survival rate. From previous studies, as well as from

the results of this study, it was established that cells from the exponential growth phase exhibited low resistance to dehydration. Due to the intense metabolic processes leading to rapid biomass growth, chromatin condensation is prevented, which is one of the protective processes of yeast cells. The thermotolerant strain *S. cerevisiae* TS1 proved to be an exception, as it exhibited similar survival rates in both the exponential and stationary growth phases. Each comparison of the anhydrobiosis reactions in strains of the same species, as well as different yeast species, as undertaken in the present study, aids in further understanding the mechanisms underlying the dehydration and rehydration phenomena.

An important aspect of the investigated phenomenon of anhydrobiosis is the influence of metal ions on the physiological activity of yeast cells. As mentioned above, the effects of calcium, magnesium, and sodium ions on yeast cells have been studied. The combination of the presence of selenium in the medium with subsequent dehydration and rehydration has not been examined thus far, although results regarding the influence of selenium on yeast cells are available.

Extensive research on the impact of selenium on the physiological activity of yeast from the genera *Saccharomyces*, *Rhodotorula*, and *Candida* was conducted by Polish scientists (Kieliszek et al. 2016, 2023). The ability of yeast biomass from *S. cerevisiae* ATCC MYA-2200, *C. utilis* ATCC 9950, and *R. mucilaginosa* MK1 LC527461.1 to bind selenium was examined, among other research purposes, for the development of supplementary preparations (e.g. as a source of selenomethionine and selenocysteine). Selenium concentrations ranging from 5-60 mg L^{-1} were applied. The toxic effects of high selenium concentrations of 20 mg L^{-1} were observed for *R. mucilaginosa*, leading to morphological changes that could potentially be mitigated by employing slow rehydration processes (which confirms the relevance of this study). The biomass yield results obtained for *S. cerevisiae* ATCC MYA-2200, *C. utilis* ATCC 9950, and *R. mucilaginosa* MK1 LC527461.1 in media supplemented with selenium showed a proportional decrease with increasing selenium dose compared to the control group.

Summarizing the provided results, it can be stated that a longer cultivation time of *R. mucilaginosa* MK1 LC527461.1 yeast (up to 96 h) and a selenium concentration of 20 mg L^{-1} were the most effective for selenium absorption into yeast cells, although a varied range of effectiveness of this process (from 8.13% to 34.43%) was observed, suggesting the possible toxic effects of high selenium concentrations (Kieliszek et al. 2023). The optimal variant during the experiment yielded 1.61 mg Se g^{-1} dry weight for *S. cerevisiae* ATCC MYA-2200 (with the addition of 10 mg Se L^{-1}) and 1.84 mg Se g^{-1} dry weight for *C. utilis* ATCC 9950 (with the addition of 20 mg Se L^{-1}) after 72 h. After analysing the percentage utilization, yield, and biomass content, the optimal selenium dose was estimated to be approximately 15 mg Se^{4+} L^{-1} for *S. cerevisiae* ATCC MYA-2200 and 25 mg Se^{4+} L^{-1} for *C. utilis* ATCC

9950, which demonstrated greater efficiency. The optimal cultivation time in both cases was determined to be 48 h.

In summary of the obtained results, the *R. glutinis* CCY 20-2-26 yeast studied in this work exhibited the highest survival rate after 48 h of cultivation and subjected to slow rehydration. Under these conditions, selenium concentrations ranging from 0.5 to 5 mg Se L^{-1} did not significantly differ from the control, while concentrations of 10-20 mg L^{-1} led to a decrease in cell survival from around 70% (for the control) to 60%, which was statistically significant. Cell losses after slow rehydration were at a level of 10% on both the first and second days of cultivation. *S. cerevisiae* ATCC 7090 yeast, similar to *R. glutinis* CCY 20-2-26 yeast, after slow rehydration and 48 h of cultivation, exhibited the highest and simultaneously stabilized survival rate at 60% (none of the tested selenium concentrations caused significant differences in survival compared to the control). Cell losses for *S. cerevisiae* ATCC 7090 were twice as high (approximately 20%) compared to the results for *R. glutinis* CCY 20-2-26. For cells after 48 h of cultivation and slow rehydration, reduced cell losses were observed for samples supplemented with selenium at concentrations of 0.5-2 mg L^{-1}.

CONCLUSIONS

The addition of selenium to the research media induces the accumulation of this element in the yeast cell biomass. It is important to remember that despite its crucial role in physiological reactions, selenium at higher concentrations can be toxic for organisms, leading to the creation of stressful conditions.

The conducted research provides new insights into the impact of selenium and the anhydrobiosis process in two different yeast strains. Studies on red yeast strains in the available literature are pioneering and can serve as a reference for future research in this area. It has been demonstrated that the *R. glutinis* CCY 20-2-26 yeast strain was more resistant to dehydration and rehydration treatments than the model *S. cerevisiae* ATCC 7090 strain.

Analysing the responses to anhydrobiosis in yeast strains exhibiting different stress tolerances may represent a significant step in understanding the mechanisms associated with this phenomenon. Such comparisons enable an understanding of the differences in the biophysical properties of yeast cell membranes subjected to stress. Studies on the effects of selenium and anhydrobiosis in different yeast strains are a valuable source of knowledge on the defence mechanisms of microorganisms against dehydration stress. Recognition of differences in resistance to these stressors opens new possibilities for biotechnology, especially in improving cell survival in industrial processes. In the future, such studies may lead to the development of new strat-

egies in yeast breeding, as well as in the production of active dried yeast, where improving cell quality and survival is one of the most critical challenges. The data presented in this study may have future applications in the biotechnological industry. Companies producing active dry yeast are constantly seeking solutions to enhance the quality of their products, including increased cell survivability.

Supplementary materials

The data generated during and/or analysed during the current study are available from the first author upon reasonable request.

Author contributions

WS: writing – original draft preparation, performed the experiments, data curation; GK: performed the experiments, methodology, data curation; AR: methodology, writing – review and editing; MK: conceptualization, methodology, supervision, investigating, source, statistical analysis, funding acquisition, writing – review and editing. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

Authors declare that they have no competing interest that could influence this work.

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