



Process Engineering Applications in Wine Technology

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Redox Potential in Wine Technology

- BEROVIC, Marin, MAVRI, Jan, WONDRA, Mojmir, KOSMERL, Tatjana, BAVČAR, Dejan. Influence of temperature and carbon dioxide on fermentation of Cabernet Sauvignon must.
Food technol. biotechnol., 2003, vol. 41, no. 4, 353-359
- PIVEC, Aleksandra, BEROVIC, Marin, CELAN, Stefan, WONDRA, Mojmir. The role of on-line redox potential measurement in Sauvignon blanc fermentation.
Food technol. biotechnol., 2002, vol. 40, no. 1, 49-55.
- PIVEC, Aleksandra, BEROVIC, Marin, WONDRA, Mojmir, CELAN, Štefan, KOŠMERL, Tatjana. Influence of temperature shock on the glycerol production in cv. Sauvignon blanc fermentation.
Vitis, 2003, vol. 42, no. 4, 205-206



**Stirred Tank Reactor
and instrumentation for *on-line* process control**

REDOX POTENTIAL

$$\mathbf{E} = \mathbf{E}_{\text{calomel}} + \mathbf{RT/ nF} \ln \mathbf{a}_{\text{oxidants}} / \mathbf{a}_{\text{reductants}}$$

$$\mathbf{E}_{\text{calomel}} = \mathbf{244 mV E_0}$$

Standard redox potencial

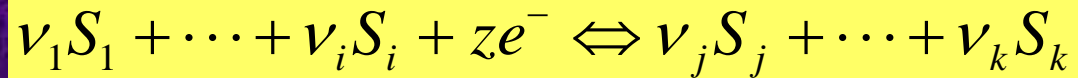
$$\mathbf{E_h} = \mathbf{E_0} + \mathbf{RT/ nF} \ln \mathbf{a}_{\text{oxidants}} / \mathbf{a}_{\text{reductants}}$$

Clark rH potential definition

$$\mathbf{rH} = \mathbf{0.0343 E_h} + \mathbf{2 pH} ; \mathbf{rH} = - \log \mathbf{pH_2} ; \mathbf{pH} = - \log \mathbf{aH_2}$$

For more complex systems

$$E_h = E^o - \frac{RT}{zF} \ln \left(\frac{\prod_i a_{red}^{v_{red}}}{\prod_i a_{ox}^{v_{ox}}} \right)$$



Product of activities of all the oxidants or reductants
in the system

$$\prod_i a_i^{v_i} \equiv a_{S_1}^{v_1} \cdot a_{S_2}^{v_2} \cdot \dots \cdot a_{S_i}^{v_i}$$

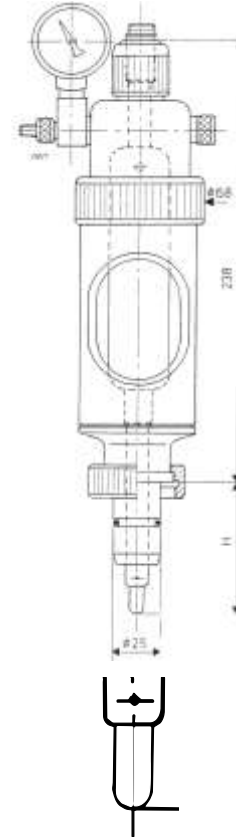
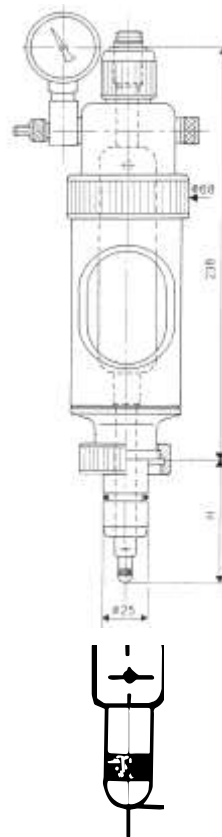
$$\prod a^{v_i}_{\text{oxidants / reductants}}$$

Redox electrode

pH electrode

Pt / calomel

glass/calomel



REDOX POTENTIAL in WINE

Redox potential in wine express intensivity and the rate of the sum of all oxydo - reductive processes

Wine represent complex oxydo-reductive system composed by :

→ **Chemical oxydo – reductive compounds :**

alcohols, aldehydes, organic (oxo & keto) acids
polyphenols, kinons, ascorbic & dehydroascorbic acid,

Ion couples Fe^{2+}/Fe^{3+} ; Cu^{+}/Cu^{2+}

→ **Metabolic activity of microbial culture and their metabolism**

→sugars (glucose) → alcohols + biomass

REDOX CHARACTERISTICS OF WINES

Premium quality wines are characterized by the lowest redox potential values

Reductive and close character wines are disposed to oxidation

Reductive non-oxydized wines $E_h = 100 - 180 \text{ mV}$; $rH=18$ do 20

Oxydized wines $E_h = 268 - 300 \text{ mV}$; $rH=24$ do 25

White bottled wines : $E_h = 275 - 280 \text{ mV}$

Red bottled wines : $E_h = 100 - 223 \text{ mV}$

REDUCTANTS:

SO_2 , ascorbic acid, cell products (cisteine , glutatione) are parameters that are decreasing redox potential and express reductive character

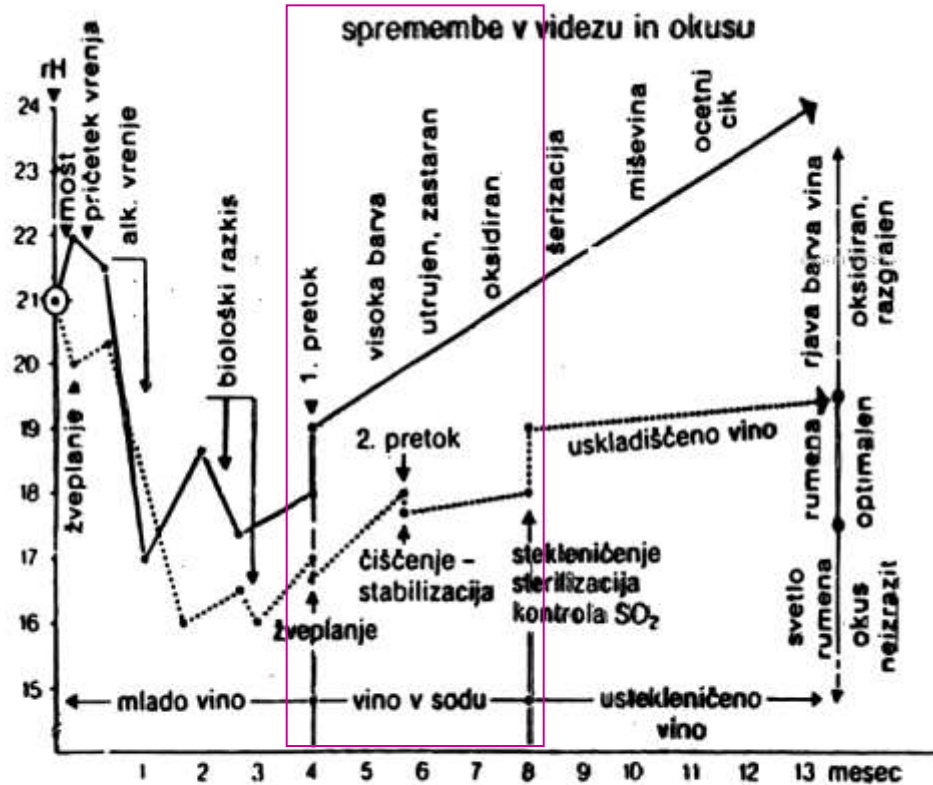
OXIDANTS:

Air oxygen, bentonites, mineral adsorbents, peroxyde

Protectors and antioxidants in fermentation :

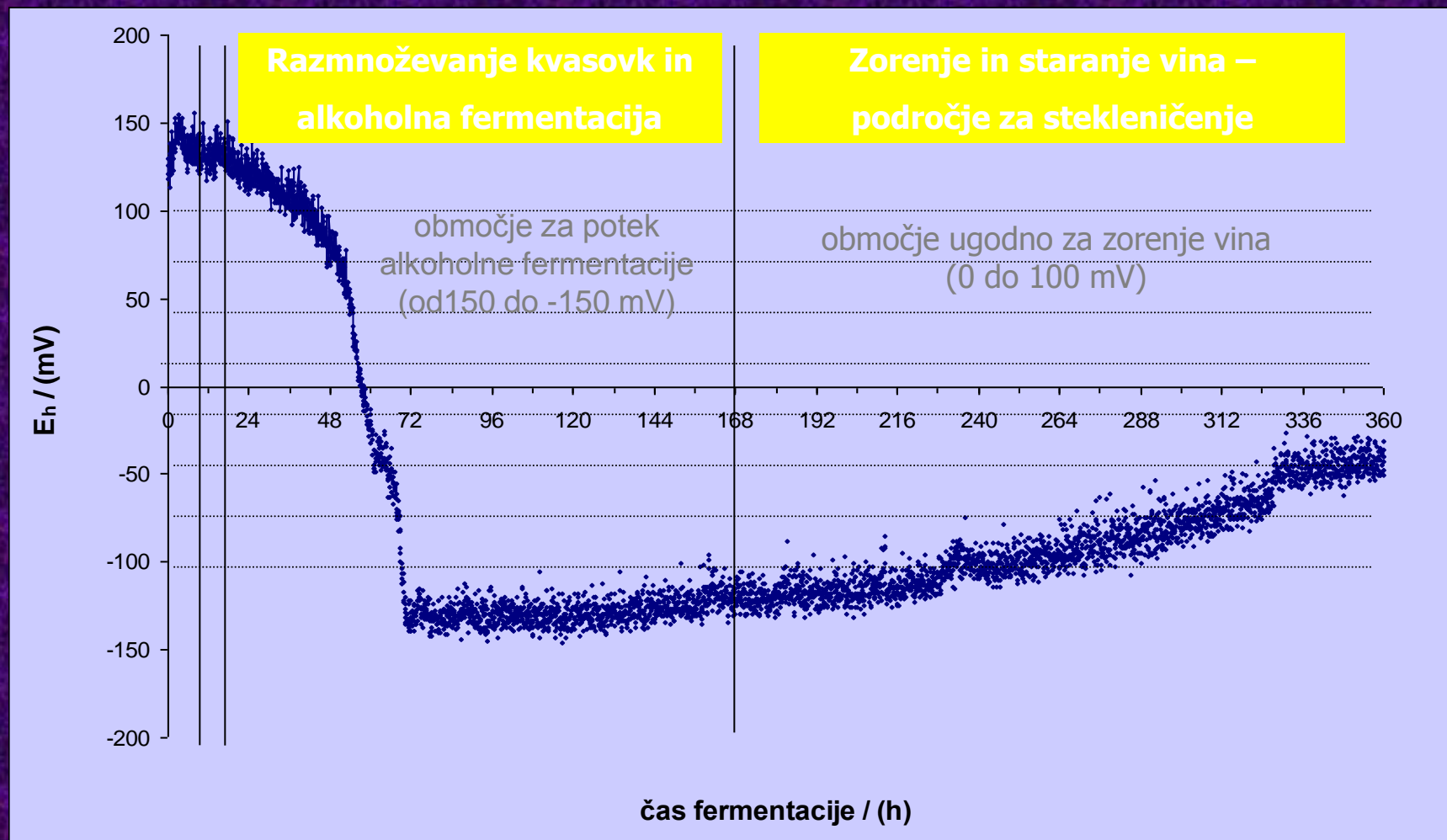
Carbone dioxyde, gaseous nitrogen are protective agents
in the pipes and fermentor head space

Redox potential in wine fermentation



Legenda: _____ nežveplan mošt
 žveplan mošt

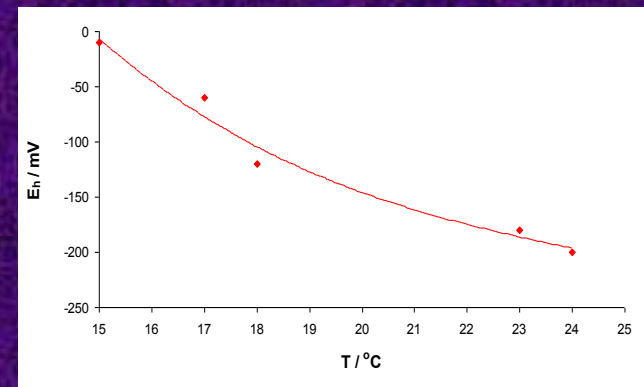
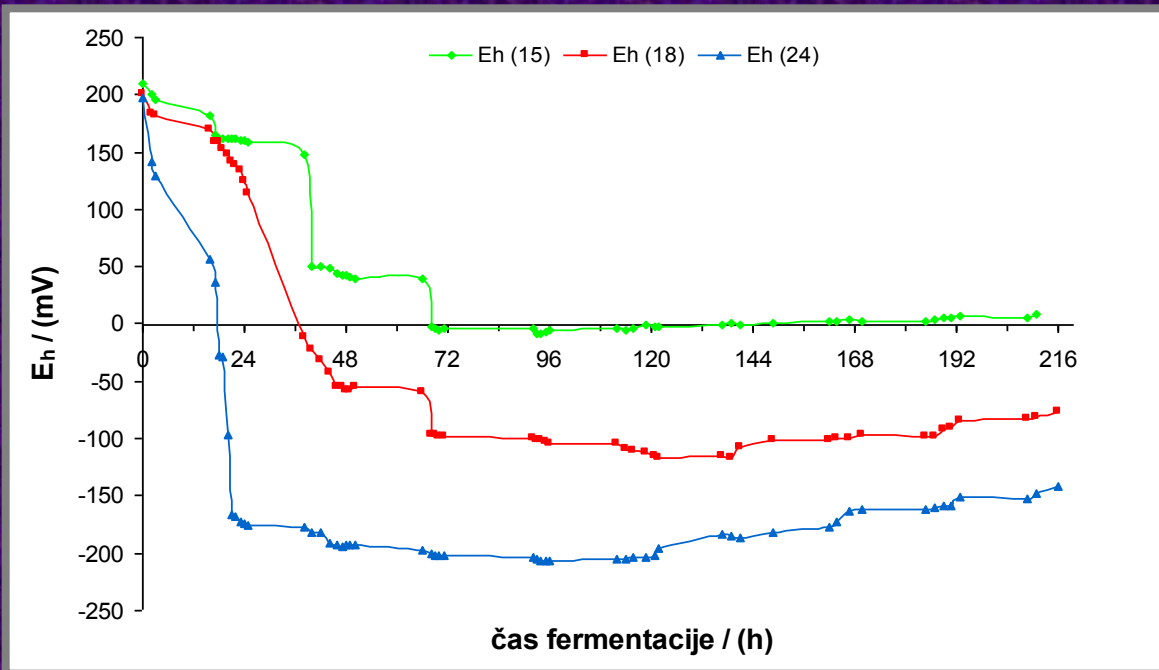
Redoks potencial med fermentacijo grozdnega mošta - 4 faze, ki jih določa značilen redoks potencial



Redoks potencial med fermentacijo mošta brez dodatka SO_2 pri 18°C

Vpliv temperature

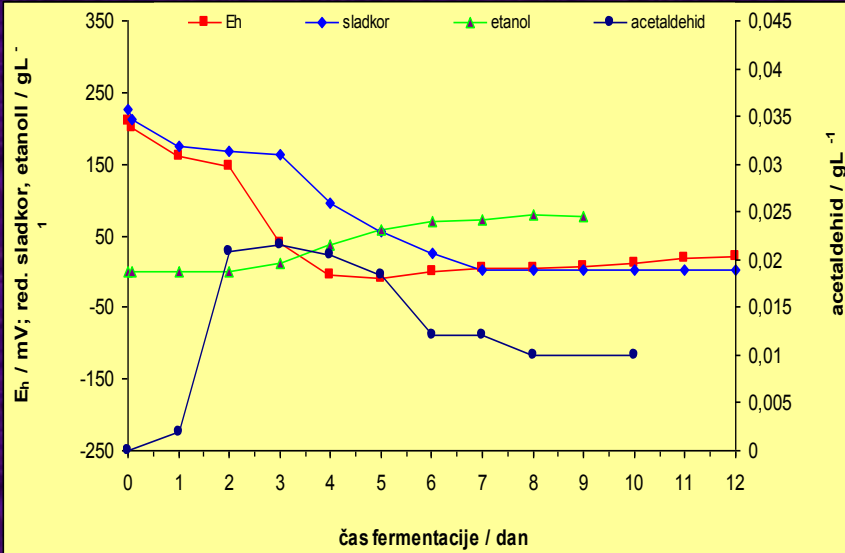
| $T [^{\circ}C]$ | začetni E_h [mV] | končni E_h [mV] | ΔE_h [mV] |
|-----------------|--------------------|-------------------|-------------------|
| 15 | 210 | -10 | 220 |
| 18 | 200 | -150 | 350 |
| 24 | 200 | -200 | 400 |



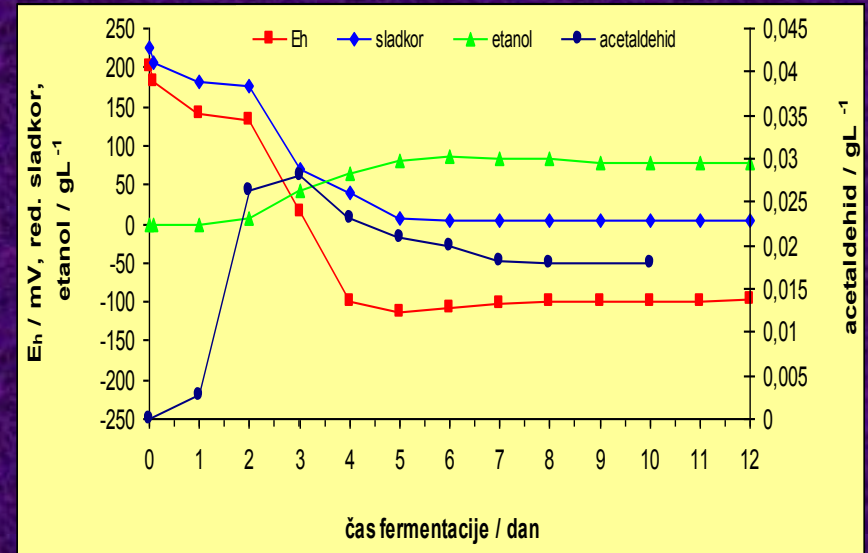
Odvisnost končnih vrednosti redoks potenciala od temperature fermentacije

Redoks potencial med procesom fermentacije pri temperaturah 15, 18 in 24 °C

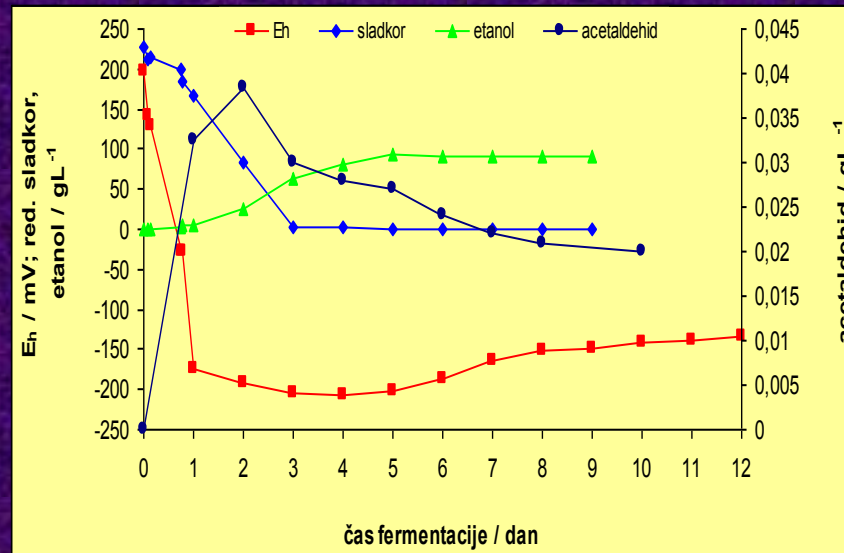
15 °C



18 °C

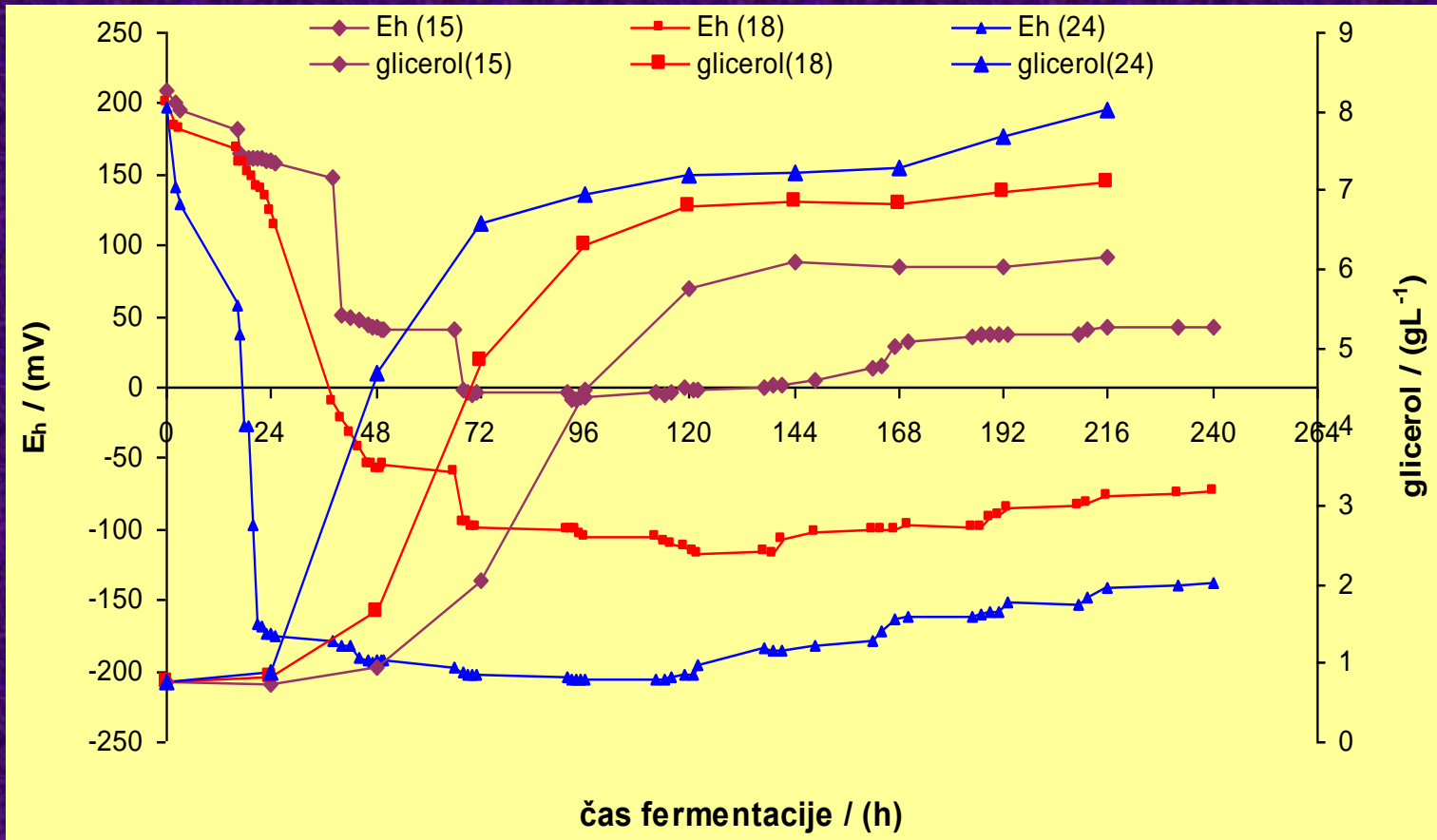


24 °C



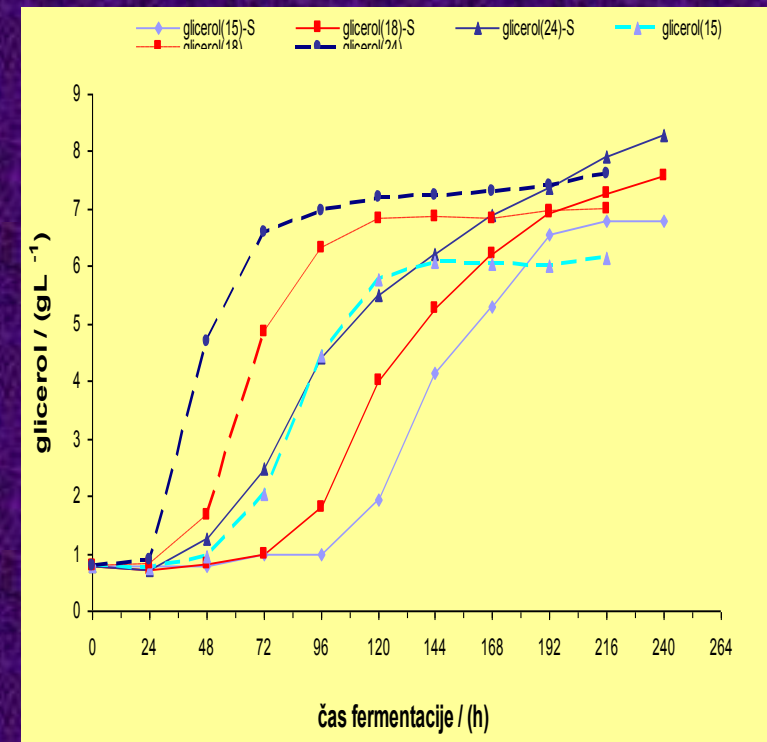
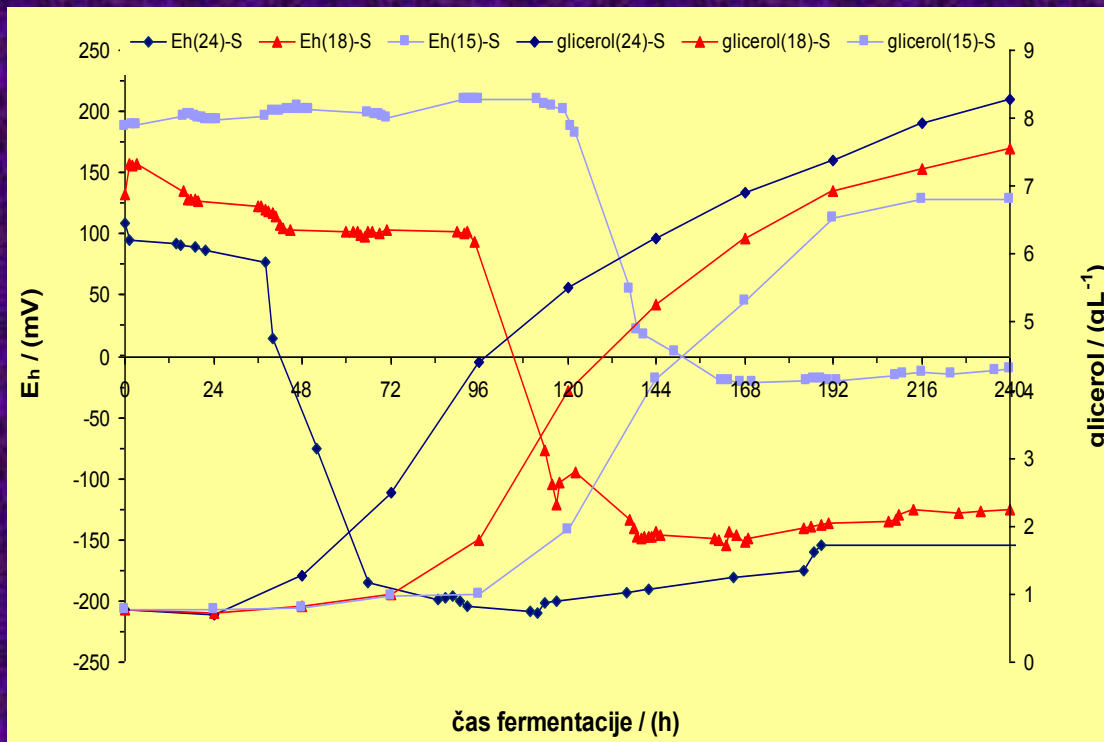
Redox potential, reductive sugars consumption, acetaldehyde and ethanol at 15, 18 in 24 °C

Redox potential and glycerol

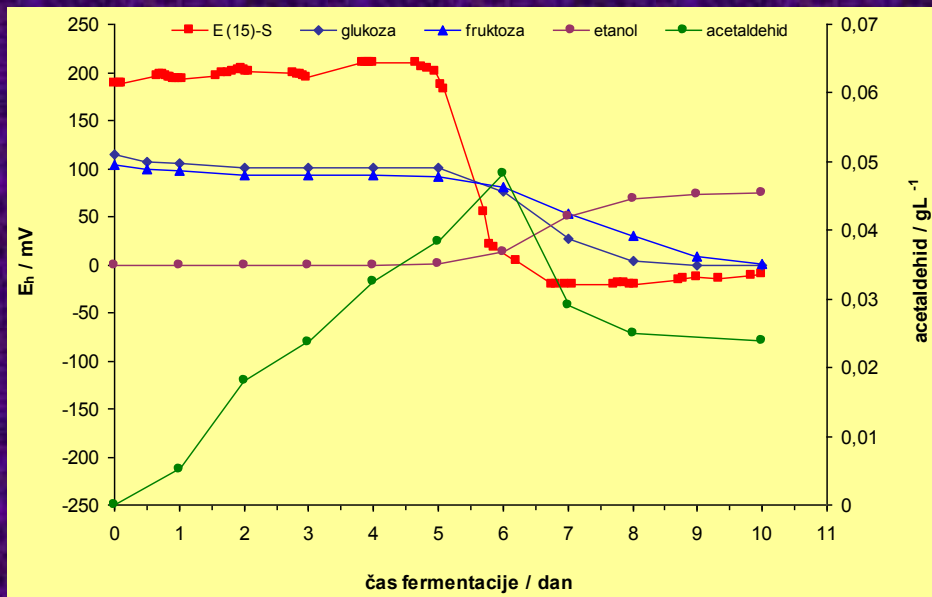


Fermentation temperatures 15, 18 and 24 °C

Redox potential and glycerol in sulfurized grape must

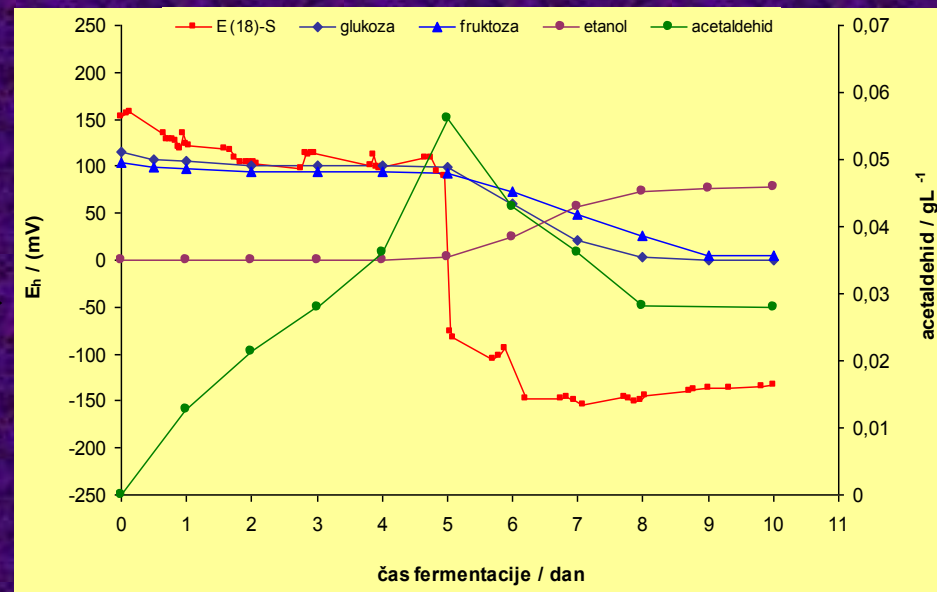


Fermentation temperatures pri 15, 18, 24 °C

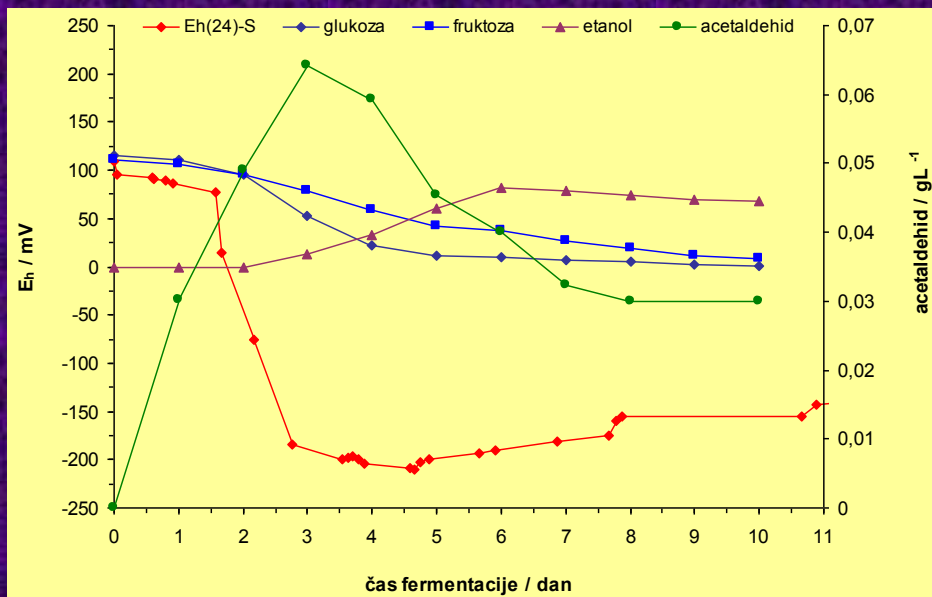


Poraba reducirajočih sladkorjev in nastanek etanola v primerjavi z redoks potencialom pri fermentaciji z SO₂ pri 15°C.

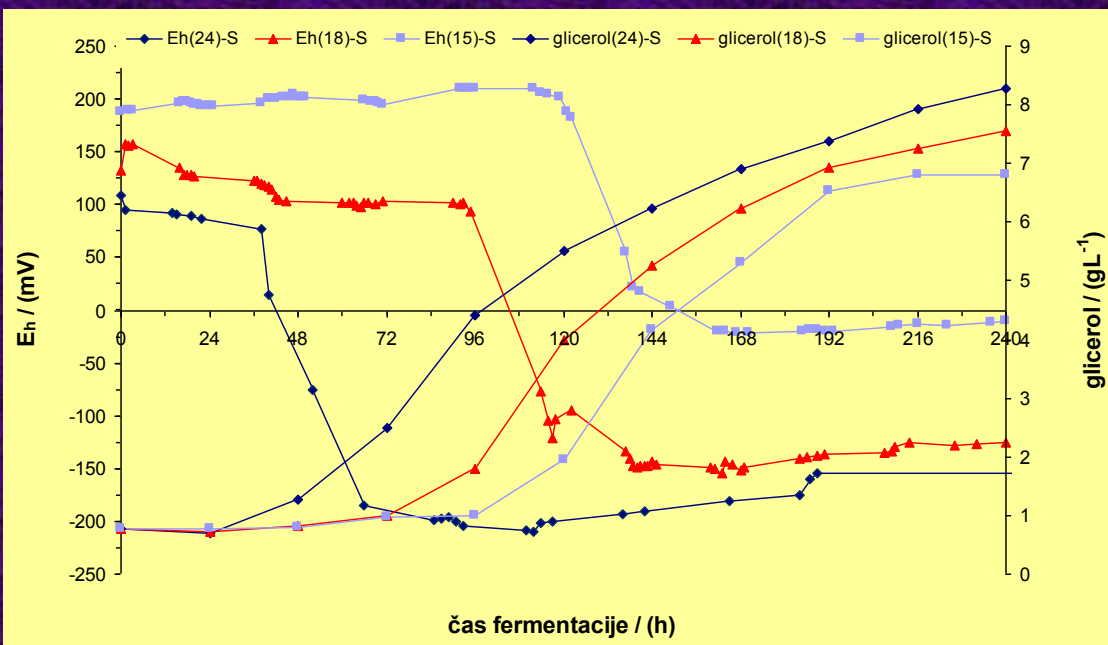
Poraba reducirajočih sladkorjev in nastanek etanola v primerjavi z redoks potencialom pri fermentaciji z SO₂ pri 18°C.



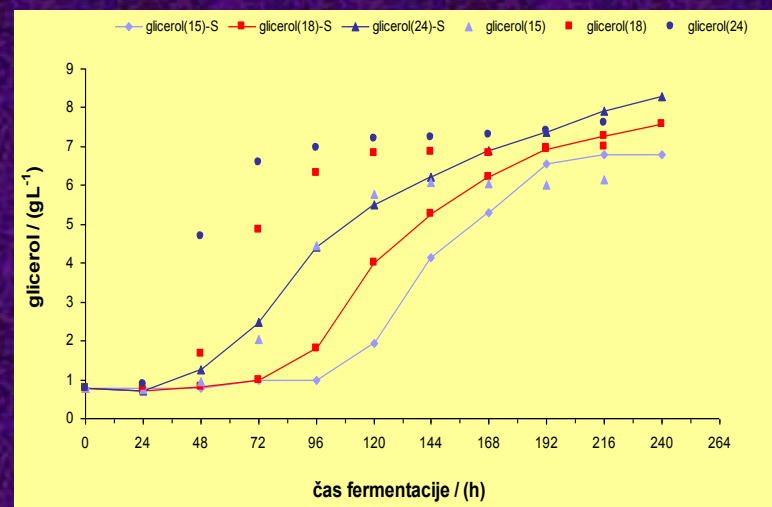
Poraba reducirajočih sladkorjev in nastanek etanola v primerjavi z redoks potencialom pri fermentaciji z SO₂ pri 24°C.



Redoks potencial in koncentracija glicerola med fermentacijami ob dodatku žveplove (IV) kisline



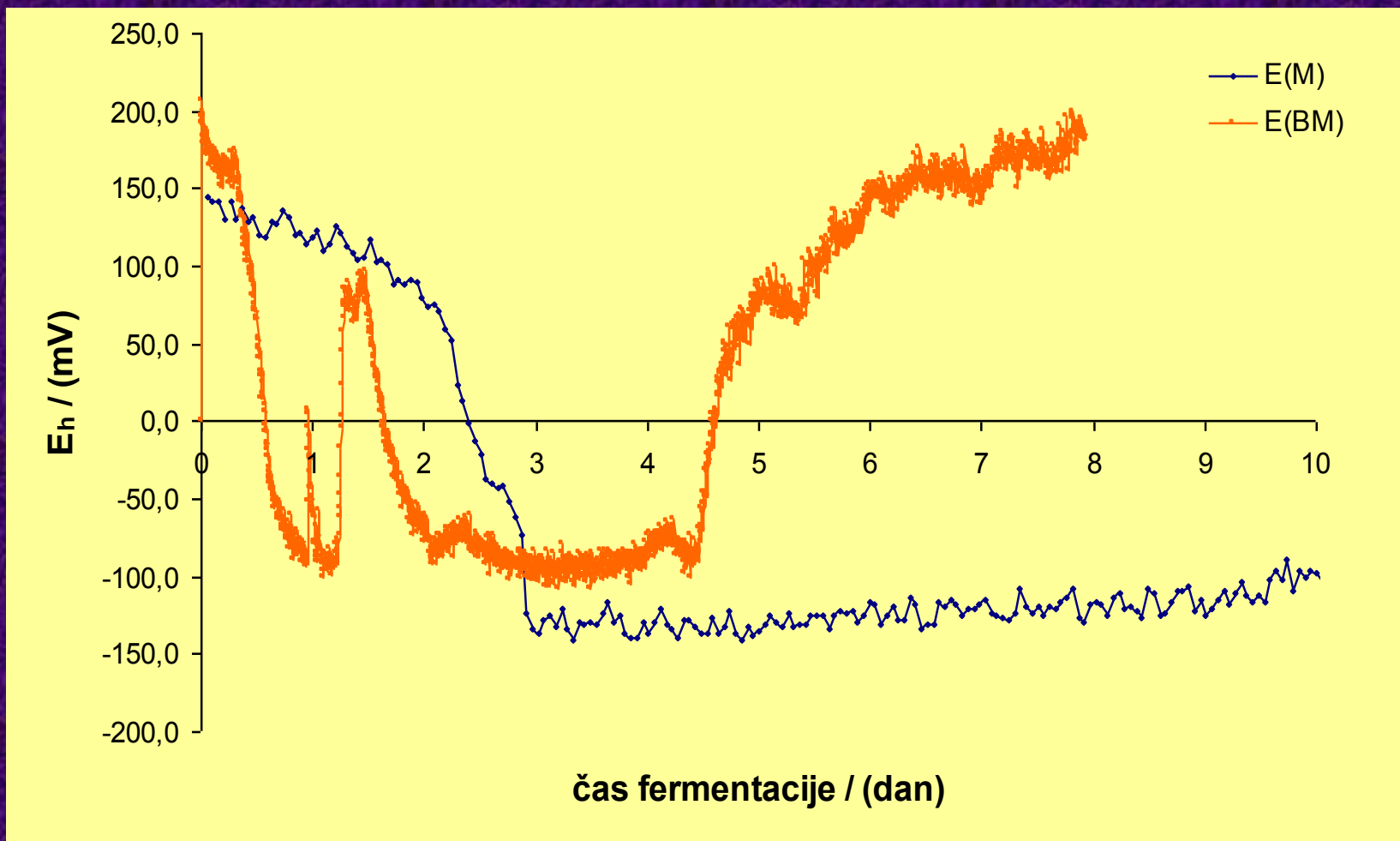
Redoks potencial in nastanek glicerola pri fermentacijah z dodano žveplove(IV) kislino pri 15, 18 in 24 °C



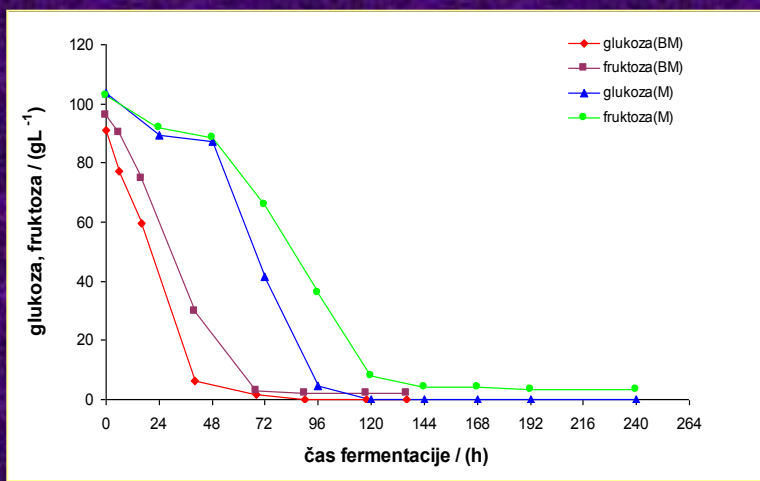
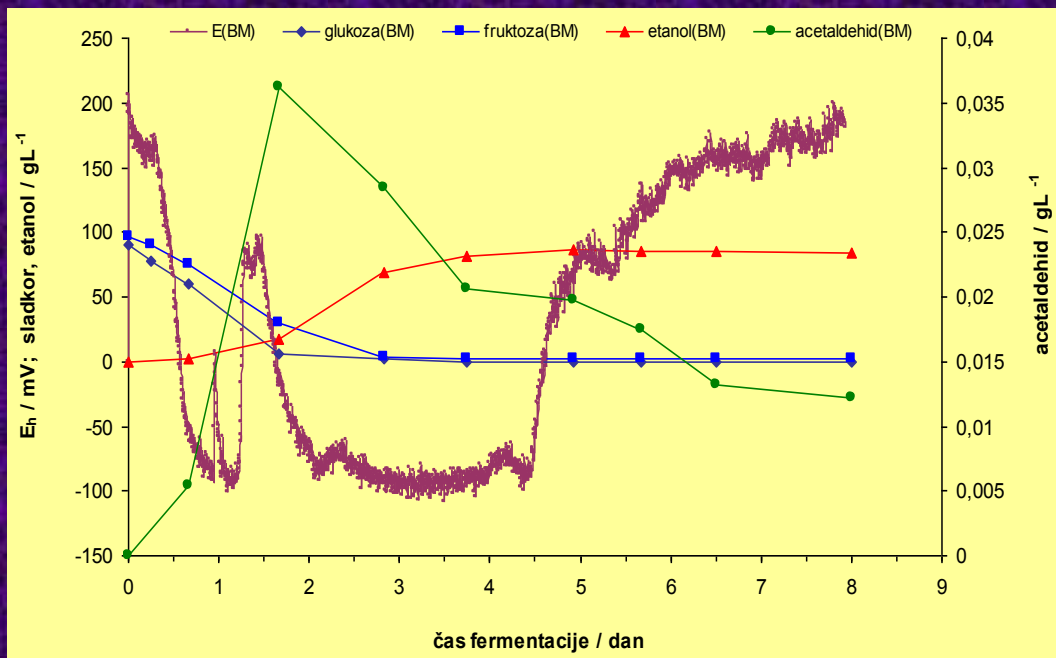
Primerjava nastajanja glicerola med fermentacijami brez in z dodanim žveplom pri 15, 18, 24 °C

REZULTATI

3. VPLIV MEŠANJA IN TEMPERATURE NA POTEK FERMENTACIJSKEGA PROCESA

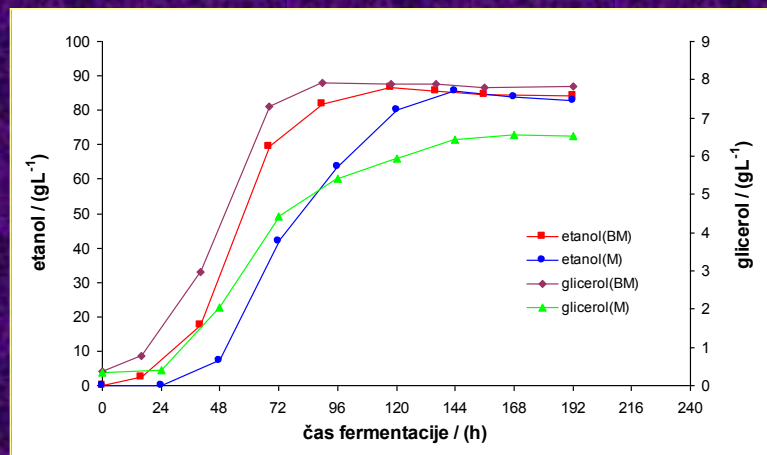


Redoks potenciala fermentacije pri 18 °C z mešanjem in redoks potencial fermentacije brez mešanja in temperaturne regulacije.

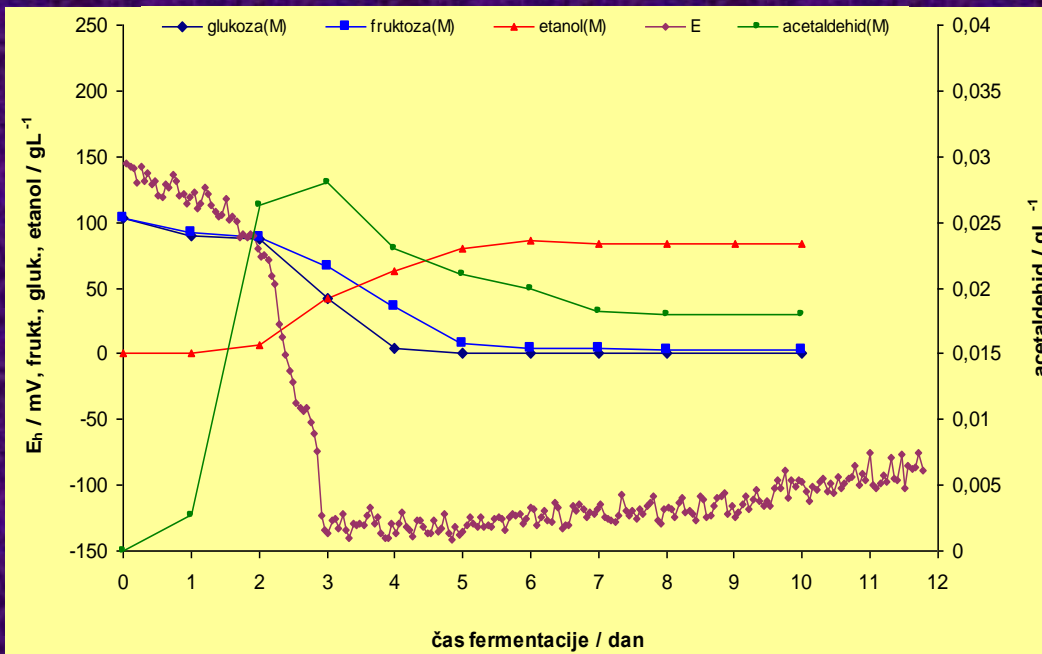


Glukoza in fruktoza med fermentacijama z mešanjem (M) in temperaturno kontrolo in brez mešanja (BM)

Redoks potencial fermentacije brez mešanja in temperaturne regulacije, glukoza, fruktoza, etanol in acetaldehid med fermentacijo



Etanol in glicerol med fermentacijama z mešanjem (M) in temperaturno kontrolo in brez mešanja (BM)

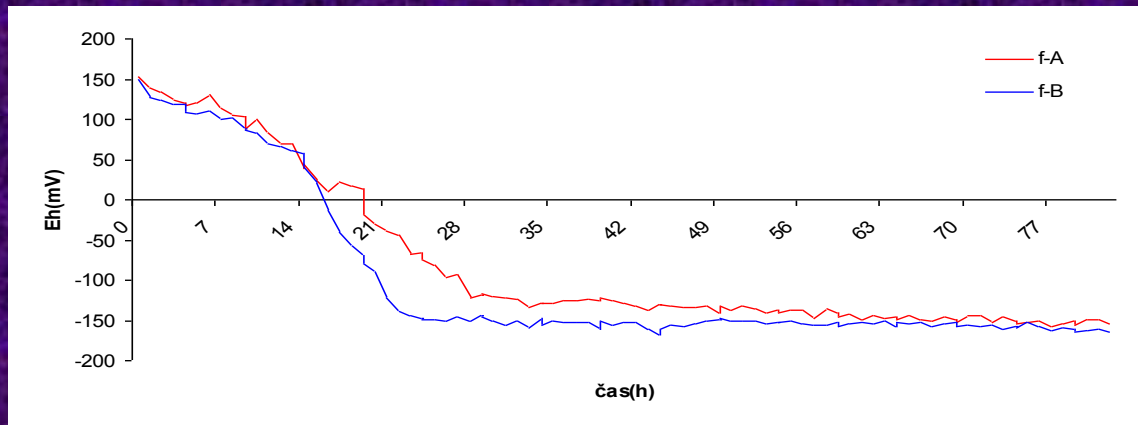


Redoks potencial fermentacije z mešanjem in temperaturno regulacijo, glukoza, fruktoza, etanol in acetaldehid

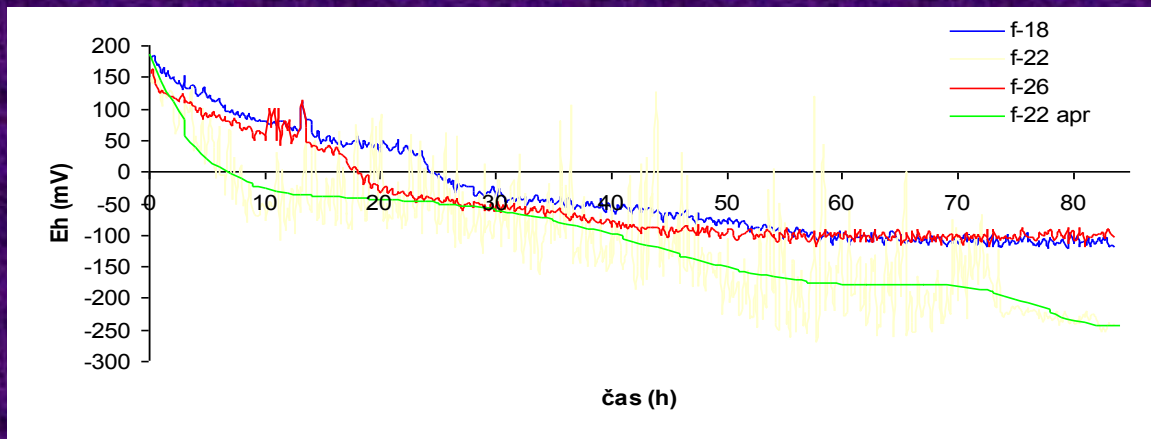
REZULTATI

4. VPLIV TEMPERATURNIH ŠOKOV NA POTEK FERMENTACIJSKEGA PROCESA IN NA NASTAJANJE GLICEROLA

Redoks potencial pri fermentaciji *kabernet sauvignona*

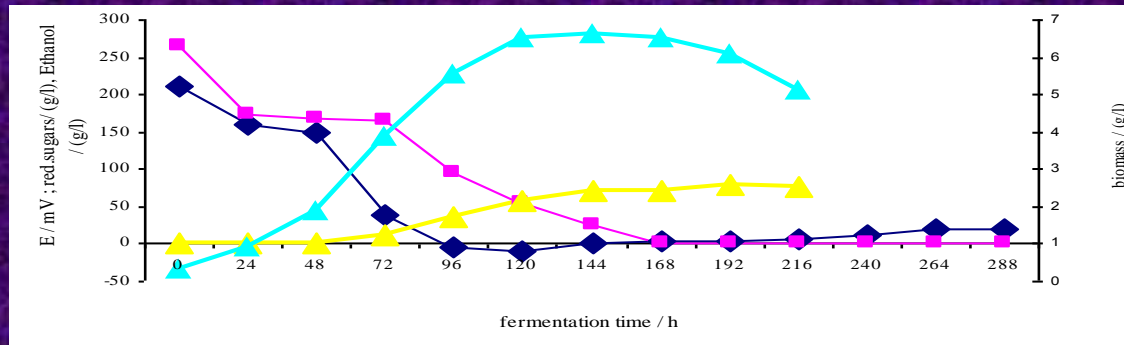


Z vpihavanjem CO₂ in brez vpihavanja CO₂

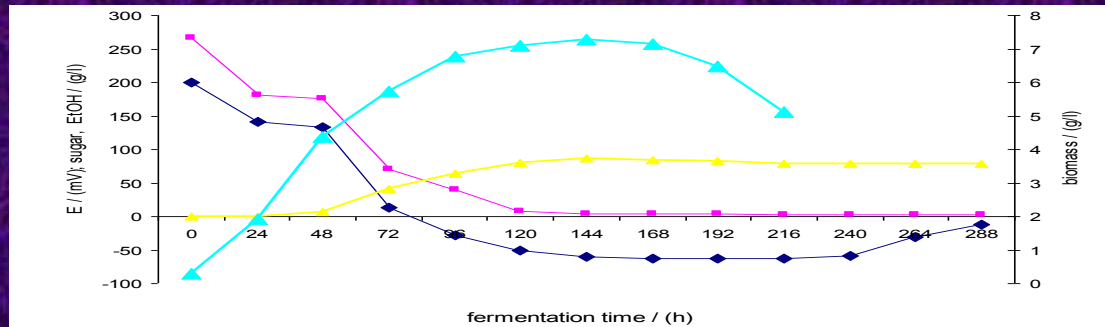


T 18 , 22, 26 ° in aproksimacija 26 °C

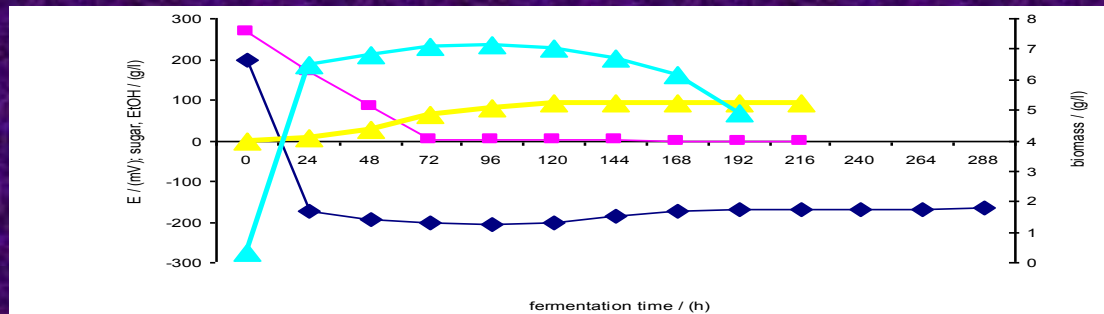
Fermentacija *sauvignona* pri T 15, 18 in 24 °C



T 15°C

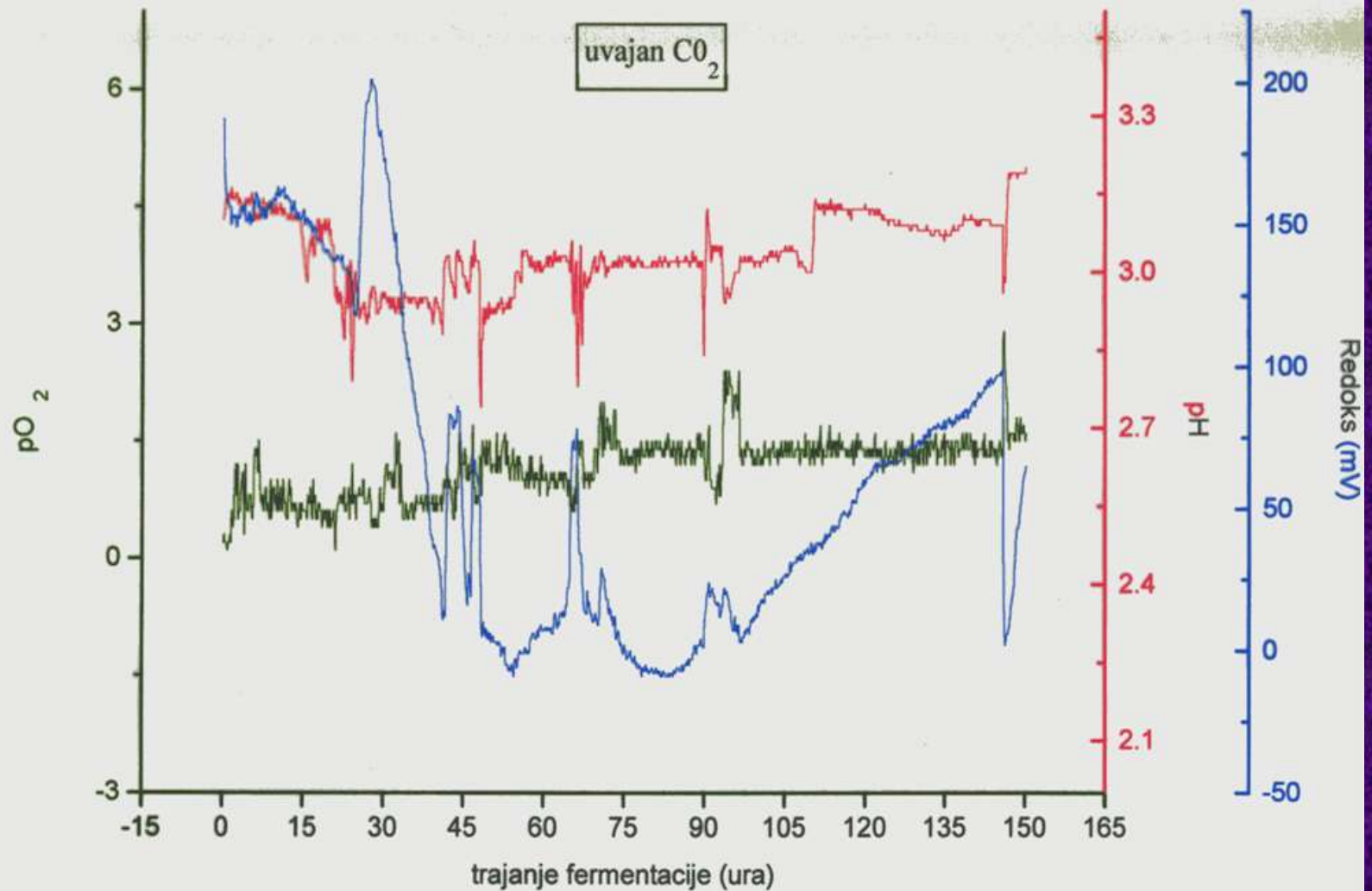


T 18°C

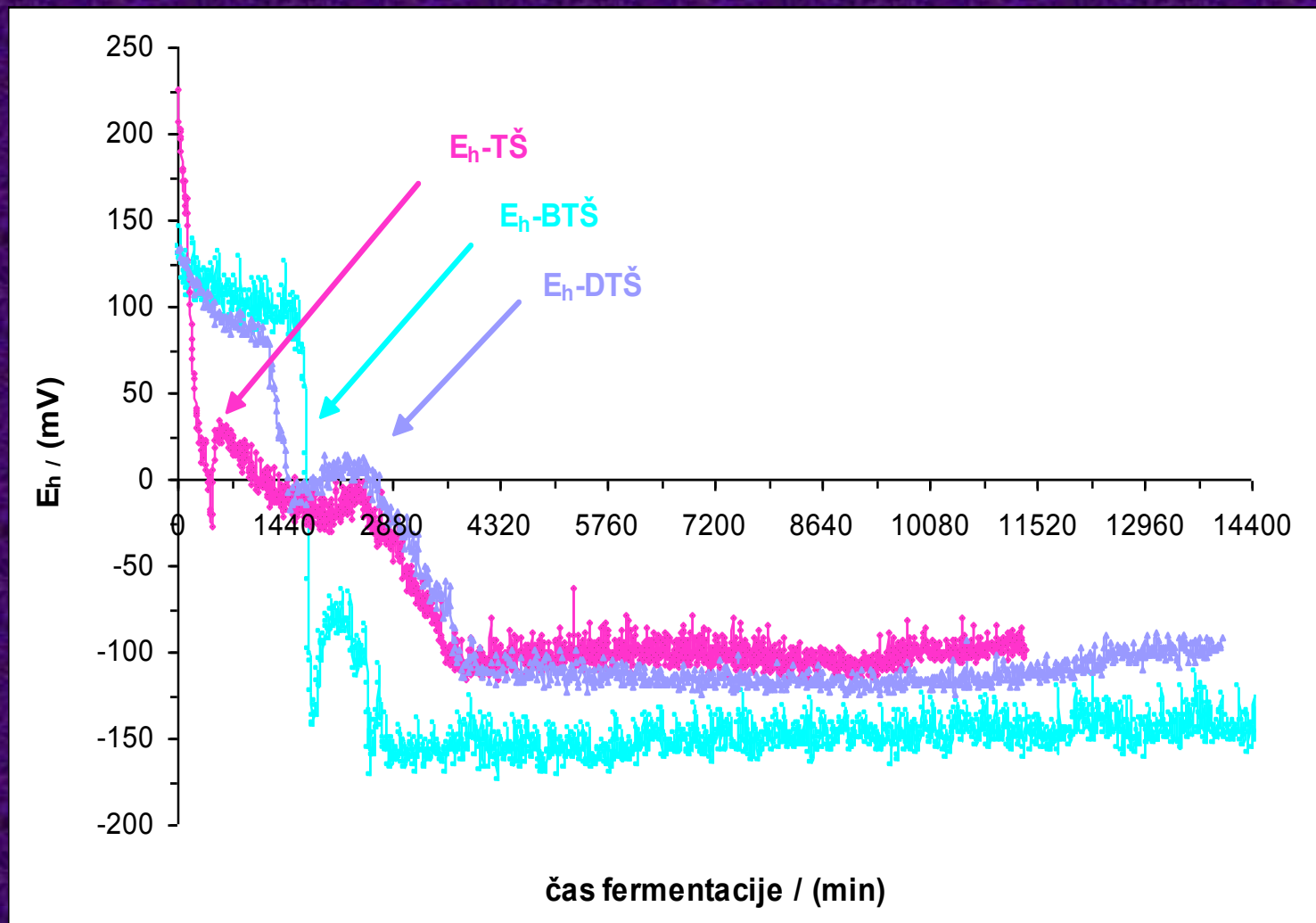


T 24°C

Fermentacija *modre frankinje* pri T 24 °C



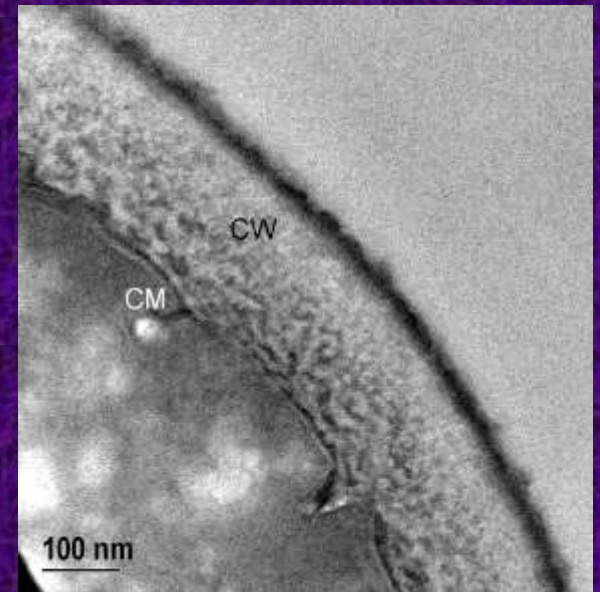
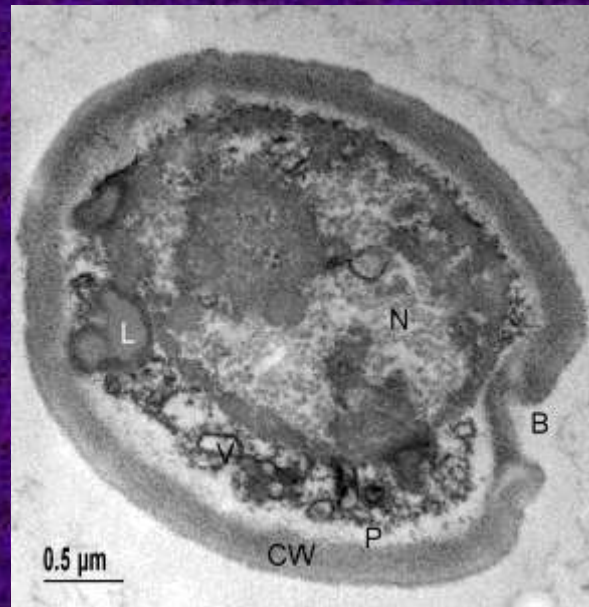
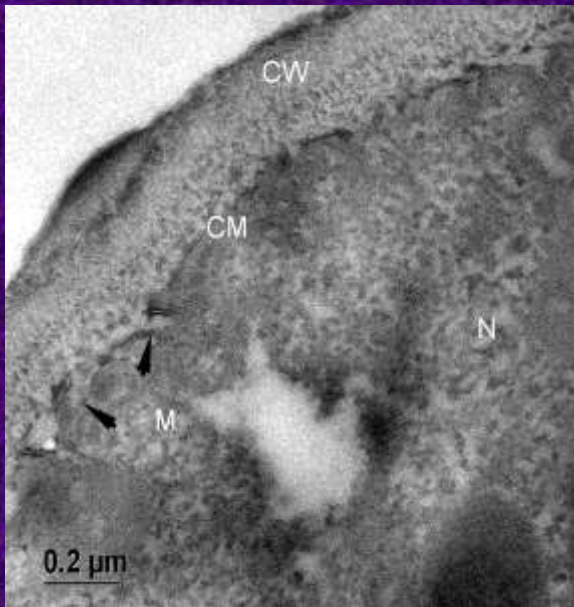
Temperaturni šok v fermentaciji cv. Sauvignon



The Influence of Galvanic Field on *Saccharomyces cerevisiae* in Grape Must Fermentation

M. BEROVIC ¹⁾, M. POTOČNIK ¹⁾ and J. STRUS ²⁾

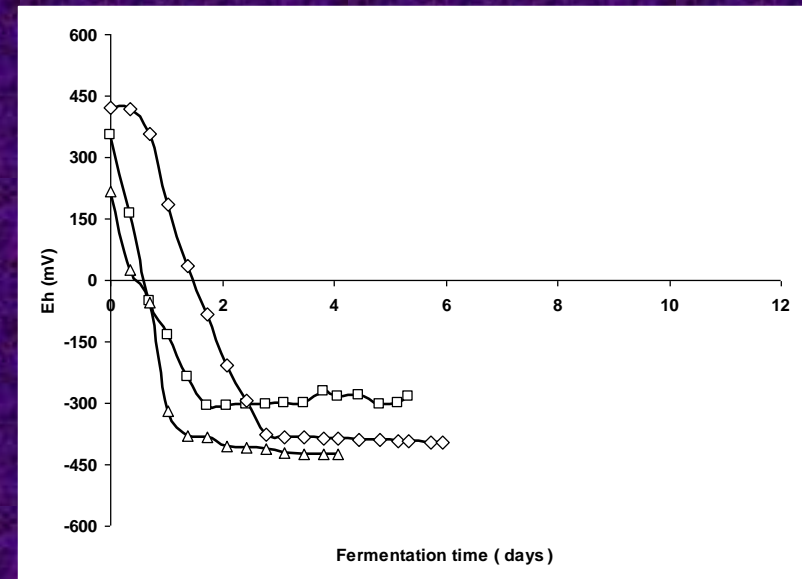
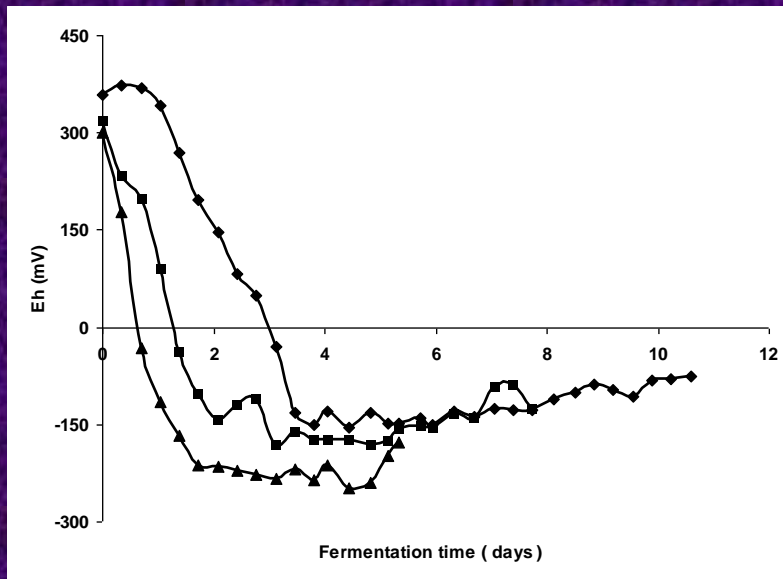
Vitis 47 (2), 117-122 (2008)



Kvasovke *S. cerevisiae* tretji dan fermentacije z elektrostimulacijo obarvane z metilen modrim.



The Influence of Galvanic Field on *Saccharomyces cerevisiae* in Grape Must Fermentation

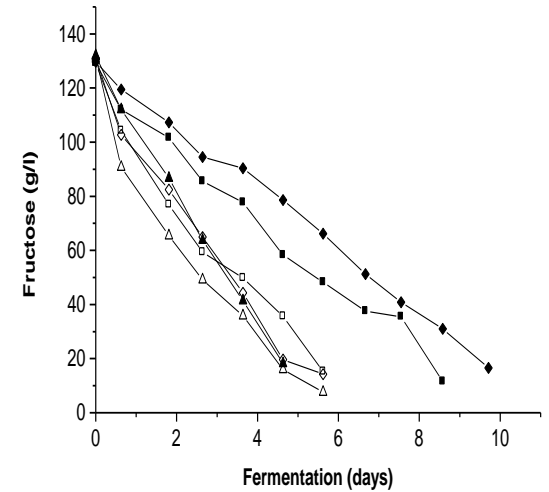
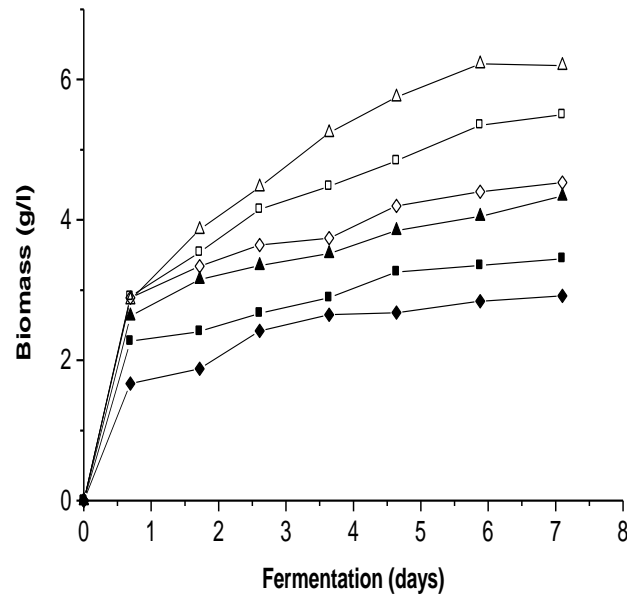
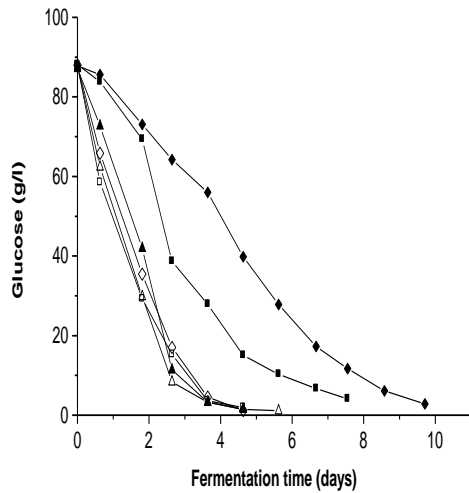


Fermentation *on-line* redox potential courses

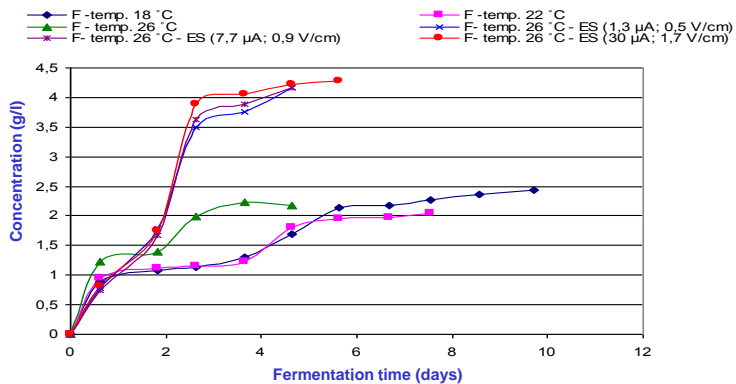
◆ T = 18, ■ 22 and ▲ 26 °C ,
without electrostimulation

◇ T = 26° C (1,3 μA) , □ T = 26° C (7,7 μA), Δ T = 26° C (30 μA),
with electrostimulation.

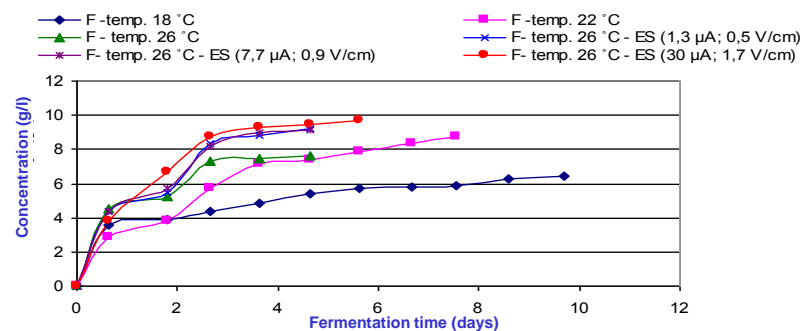
The Influence of Galvanic Field on *Saccharomyces cerevisiae* in Grape Must Fermentation



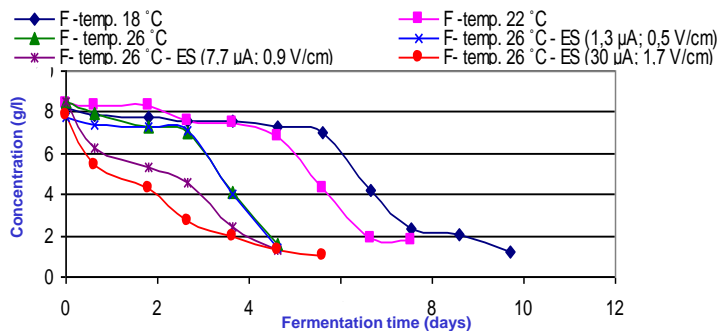
Lactic acid



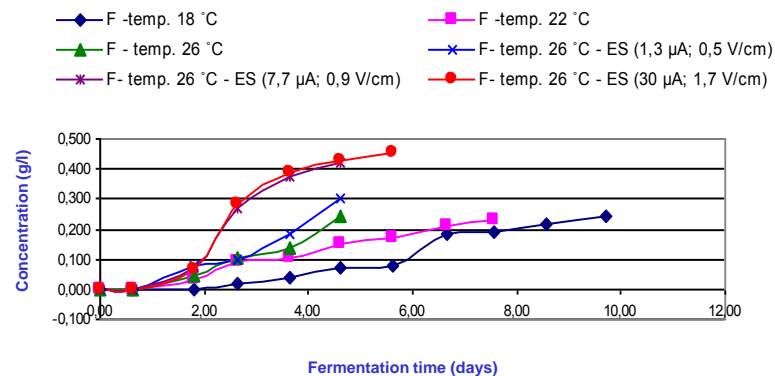
Glycerol



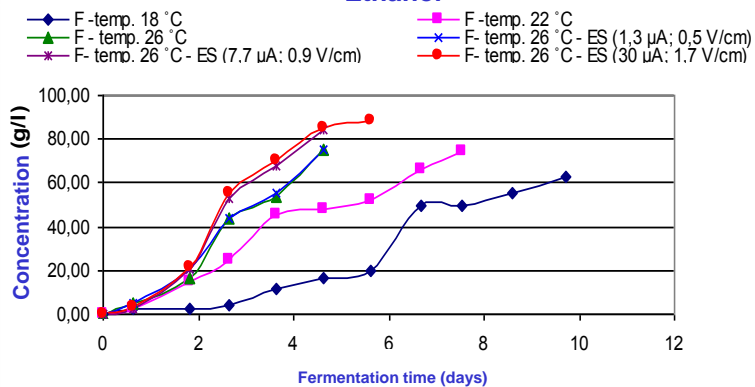
Malic acid



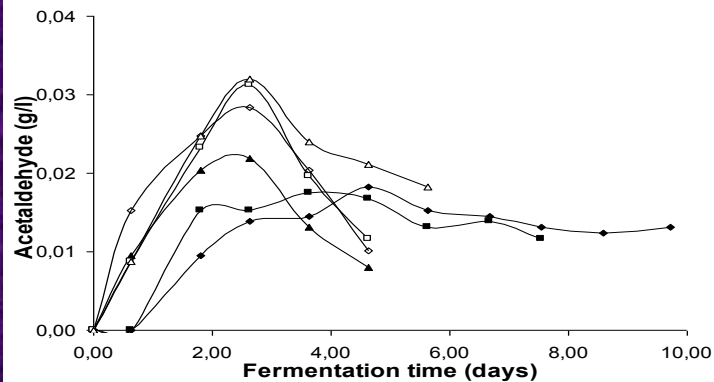
Iso-amylalcohol



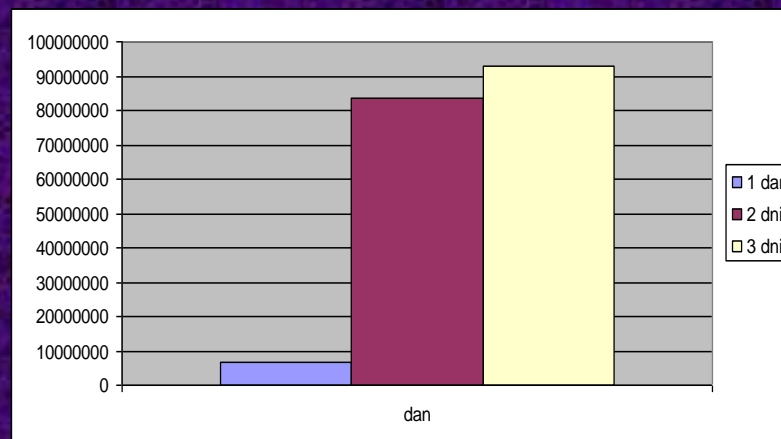
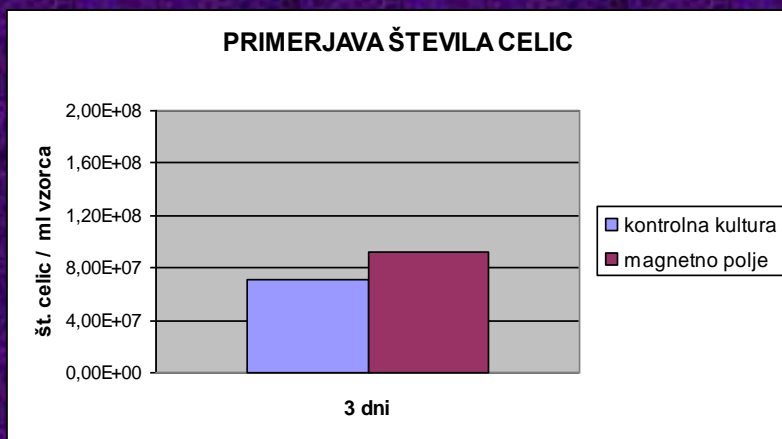
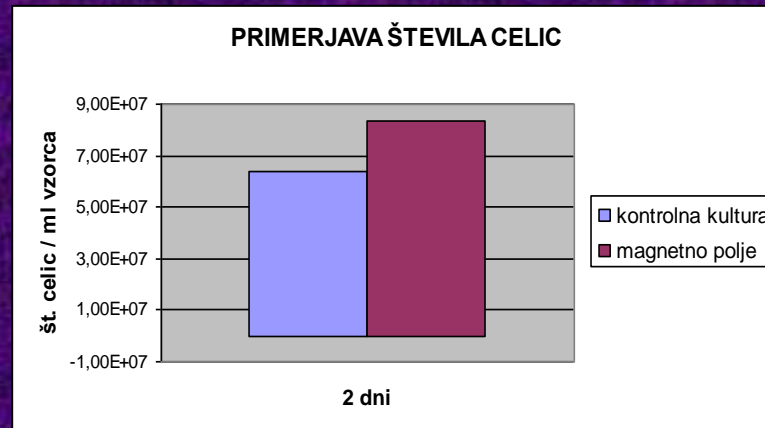
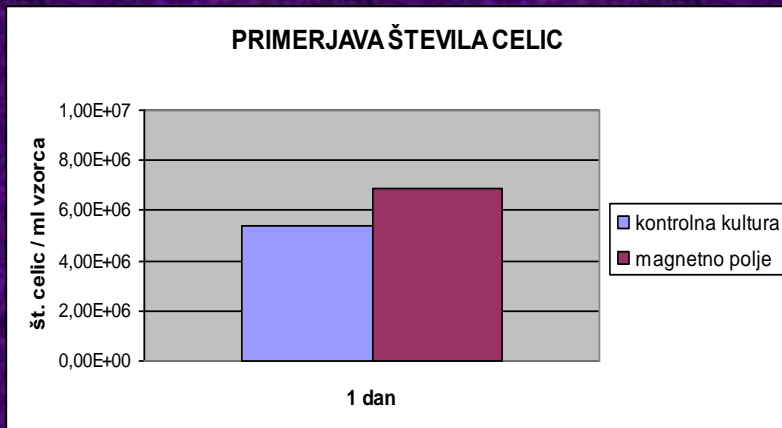
Ethanol



Acetaldehyde

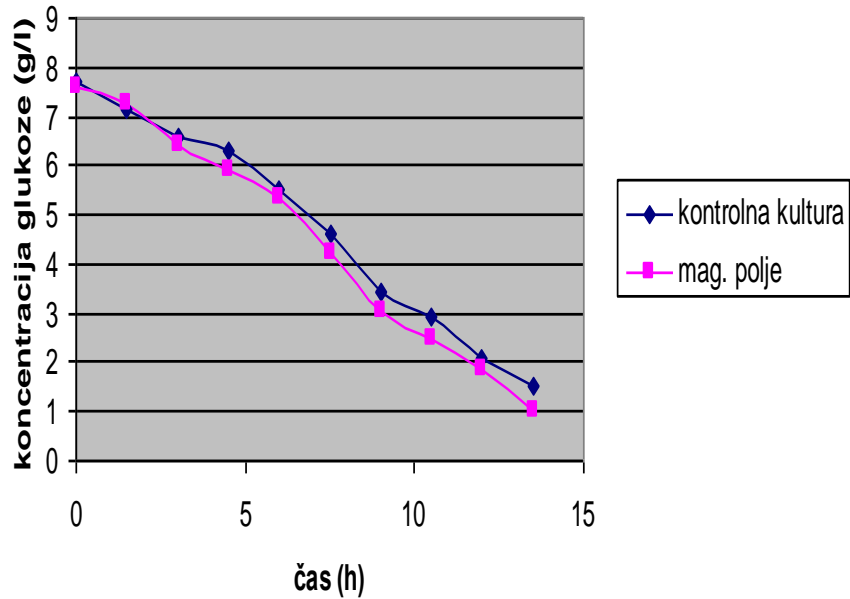


REZULTATI

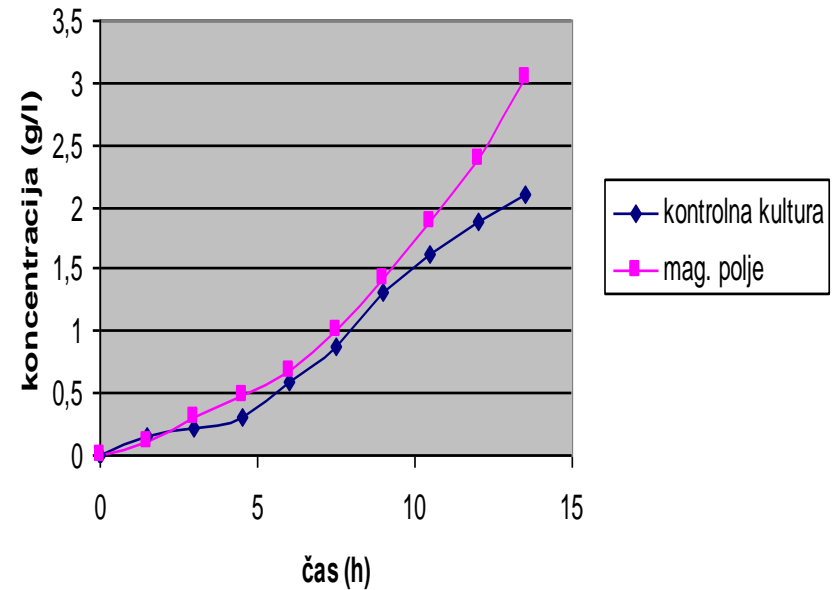


REZULTATI V KOMPLEKSNEM GOJIŠČU

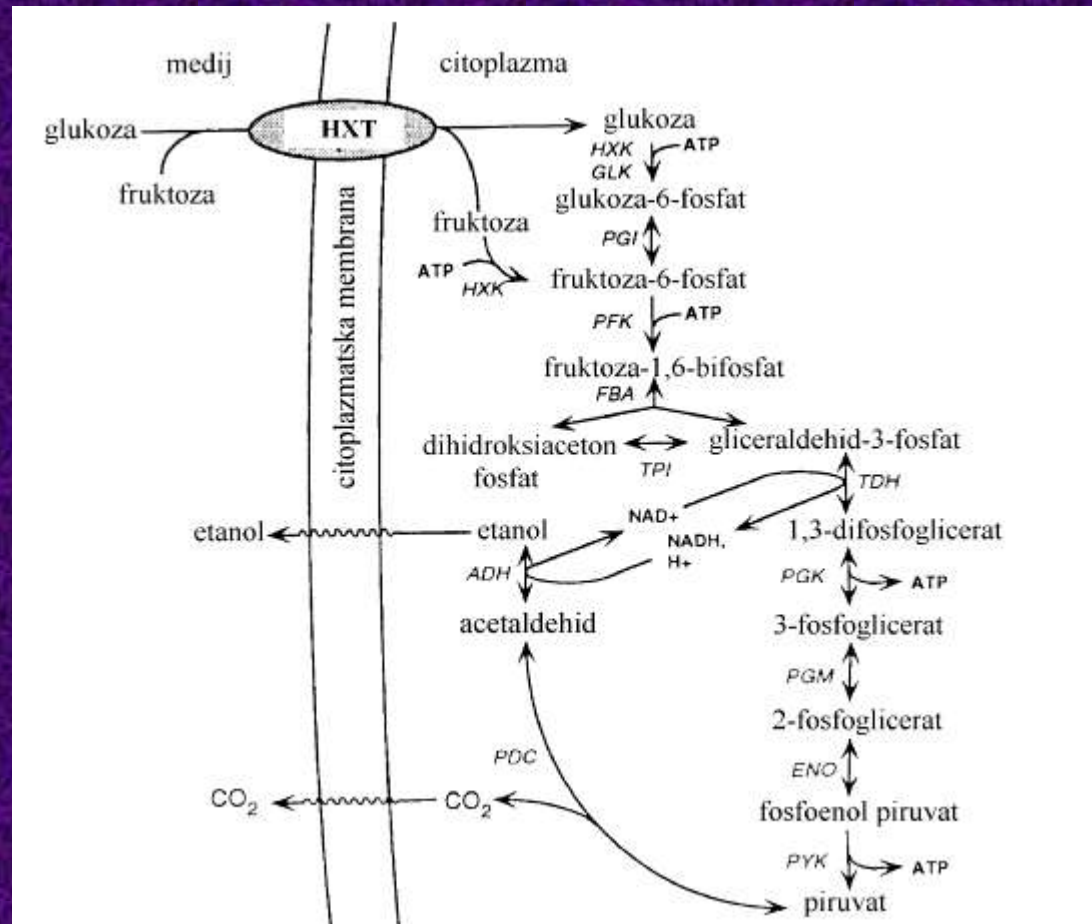
KONCENTRACIJA GLUKOZE



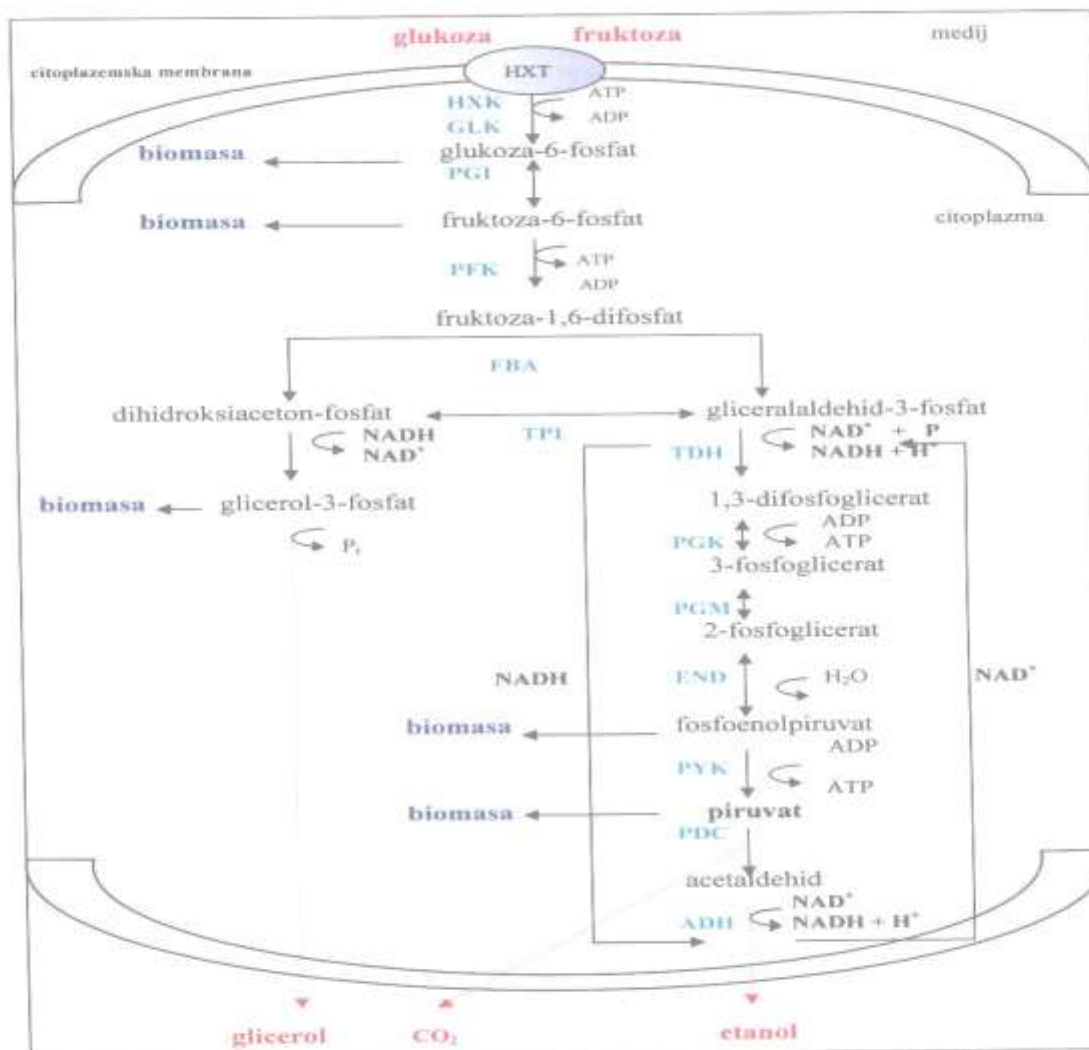
KONCENTRACIJA ETANOLA



ALKOHOLNA FERMENTACIJA



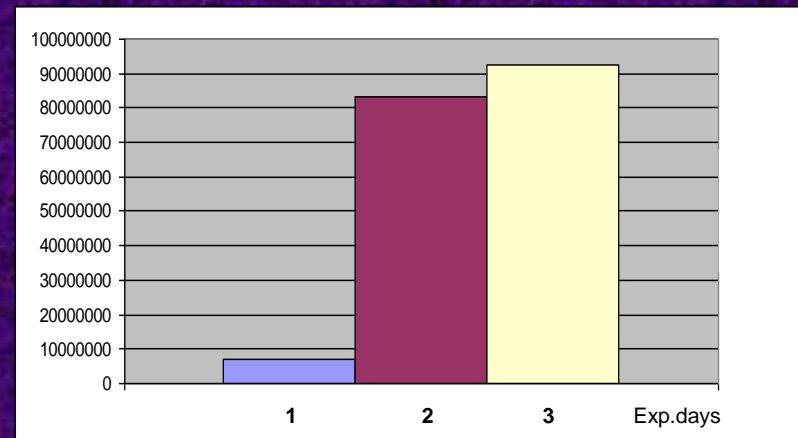
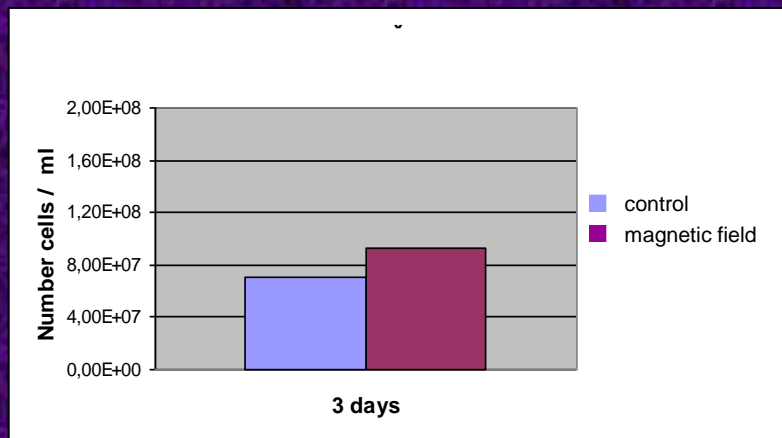
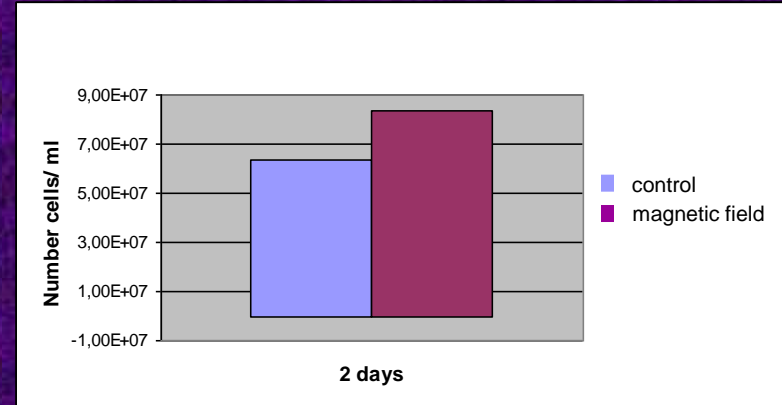
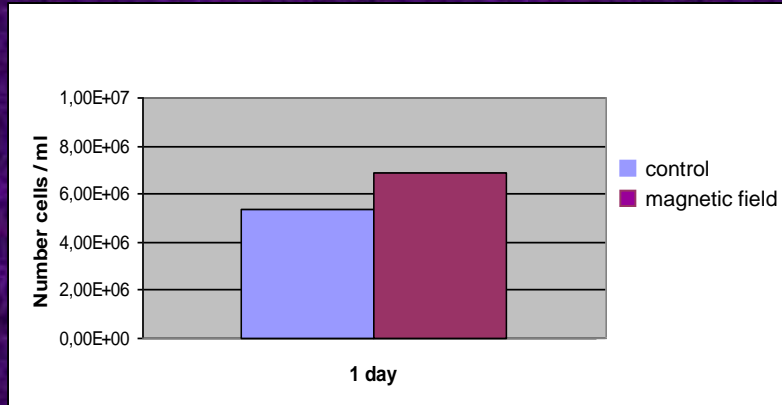
Glikoliza in nastajanje etanola



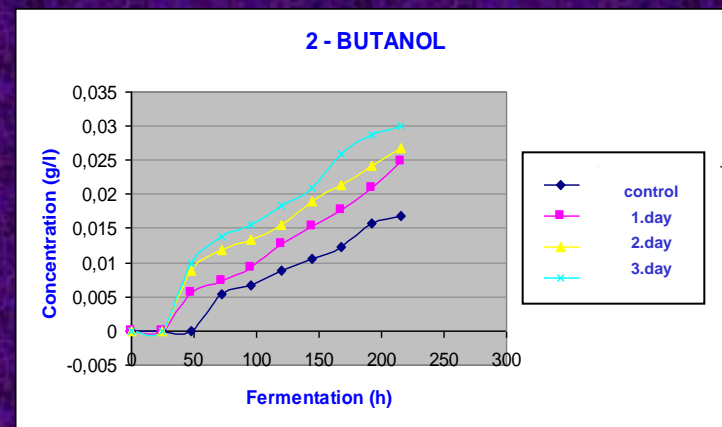
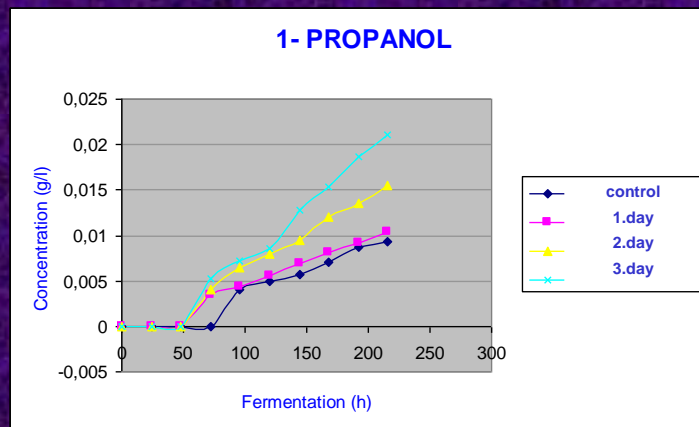
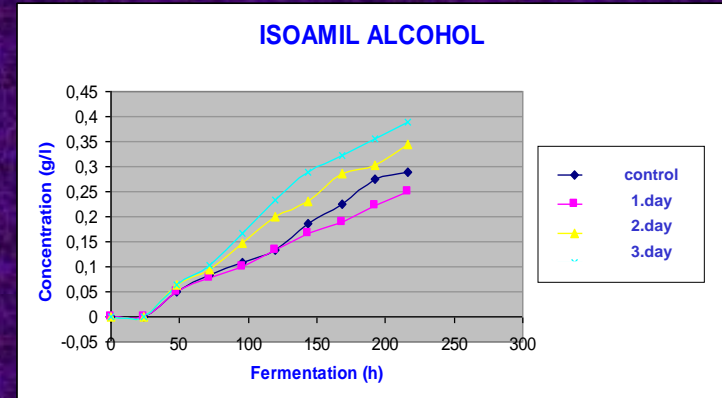
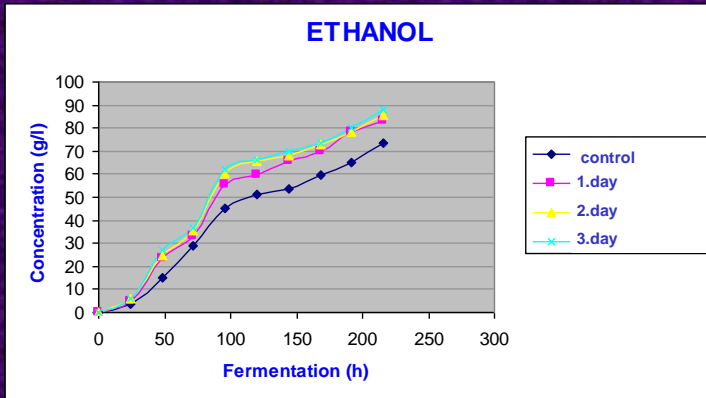
Slika 5.: Shematični prikaz bioprocesa glikolize in alkoholne fermentacije.

Pomen kratic na sliki: HXT (prenašalni protein za heksozo), HXK (heksokinaza), GLK (glukokinaza), PGI (fosfoglukoizomeraza), PFK (fosfofruktokinaza), FBA (aldolaza), TPI (triozafosfat izomeraza), TDH (gliceraldehid-3-fosfat dehidrogenaza), PGK (fosfoglicerat kinaza), PGM (fosfoglicerat mutaza), ENO (enolaza), PYK (piruvat kinaza), PDC (piruvat dekarboksilaza), ADH (alkohol dehidrogenaza), (Boulton *in sod.*, 1996)

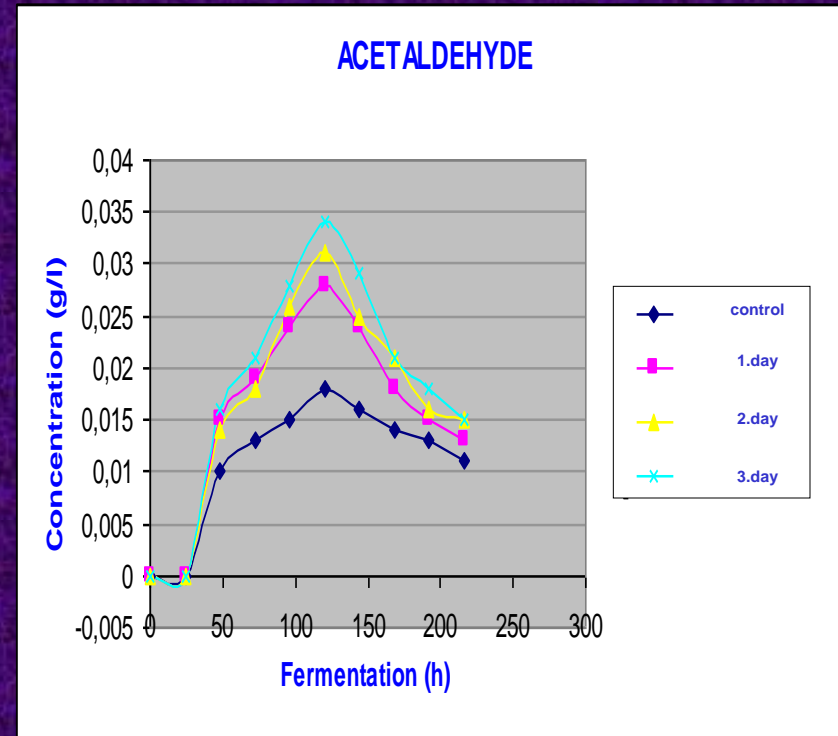
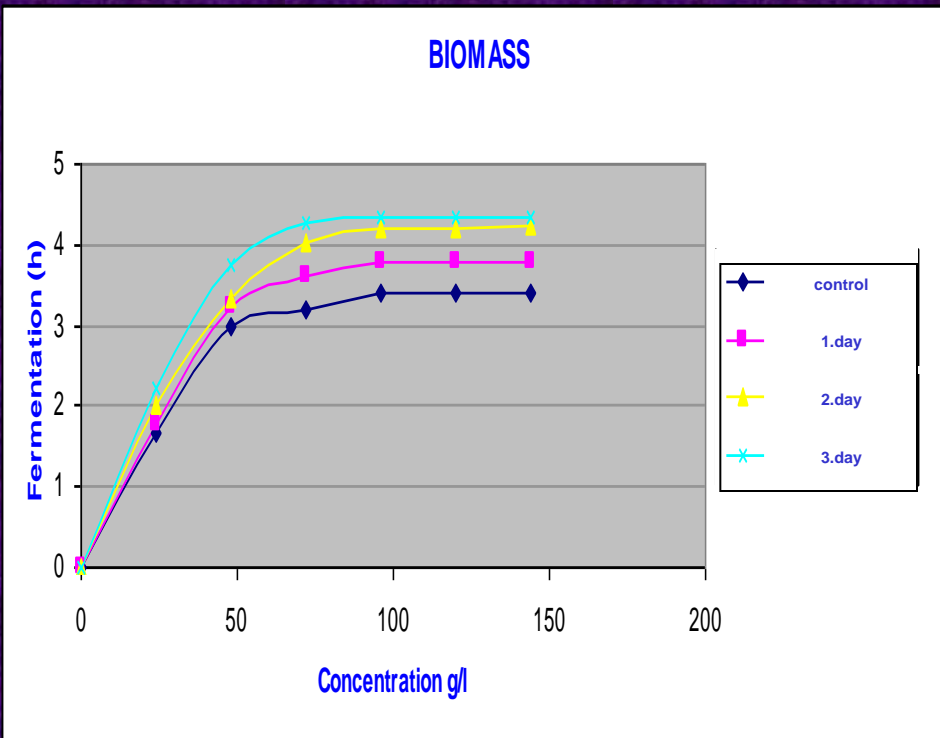
Influence of static magnetic field on *Saccharomyces cerevisiae* metabolism



Influence of static magnetic field on *Saccharomyces cerevisiae* metabolism

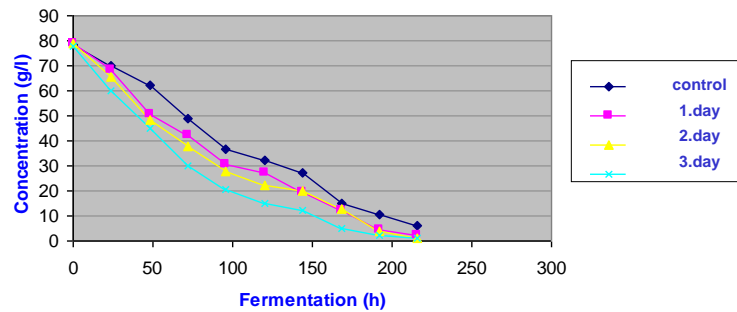


Influence of static magnetic field on *Saccharomyces cerevisiae* metabolism

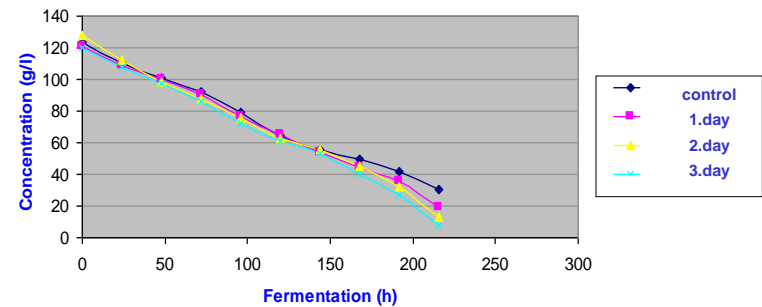


Influence of static magnetic field on *Saccharomyces cerevisiae* metabolism

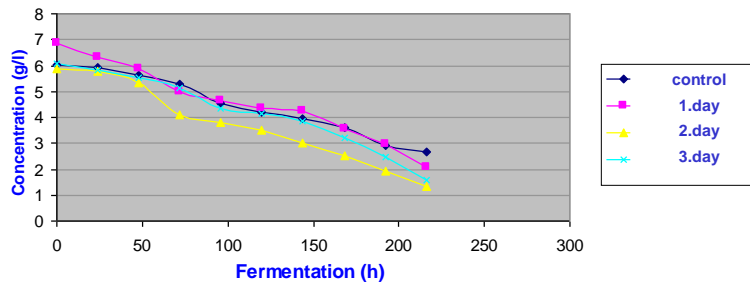
GLUCOSE



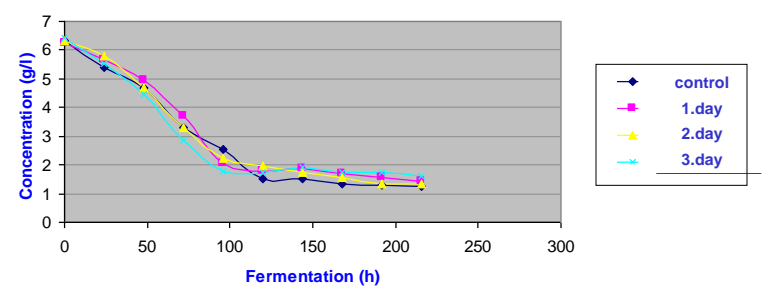
FRUCTOSE



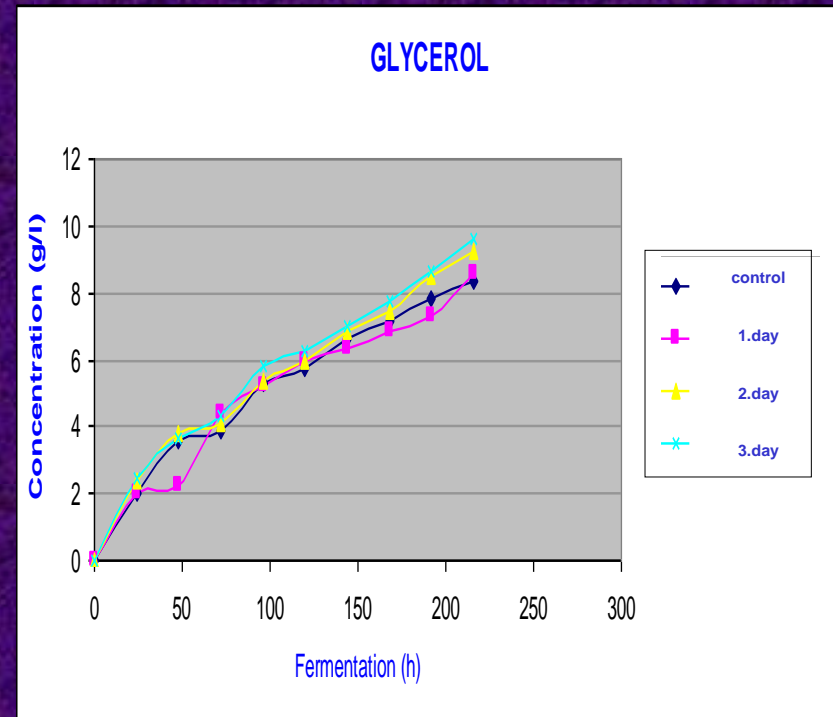
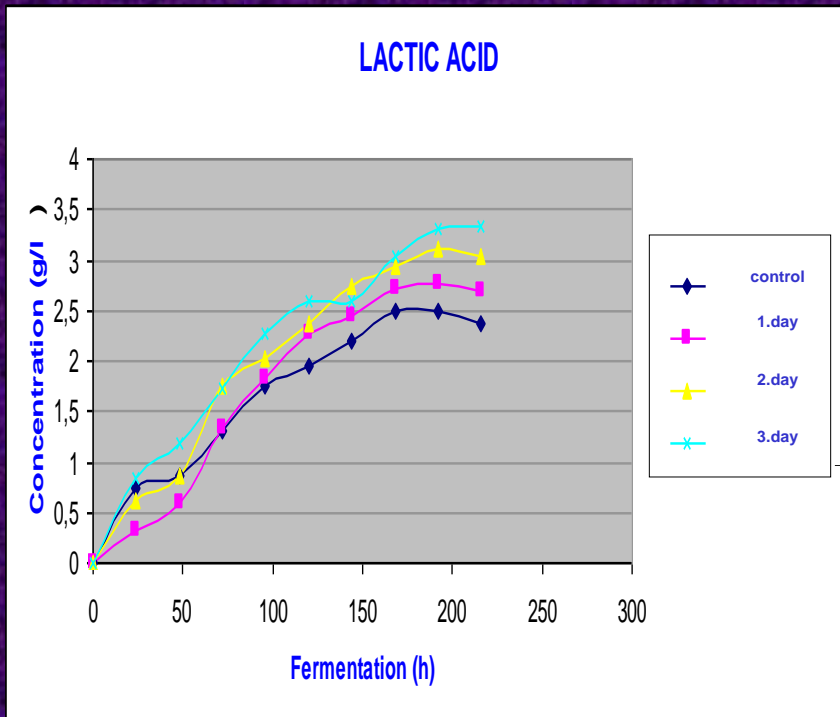
TARTARIC ACID



MALIC ACID



Influence of static magnetic field on *Saccharomyces cerevisiae* metabolism

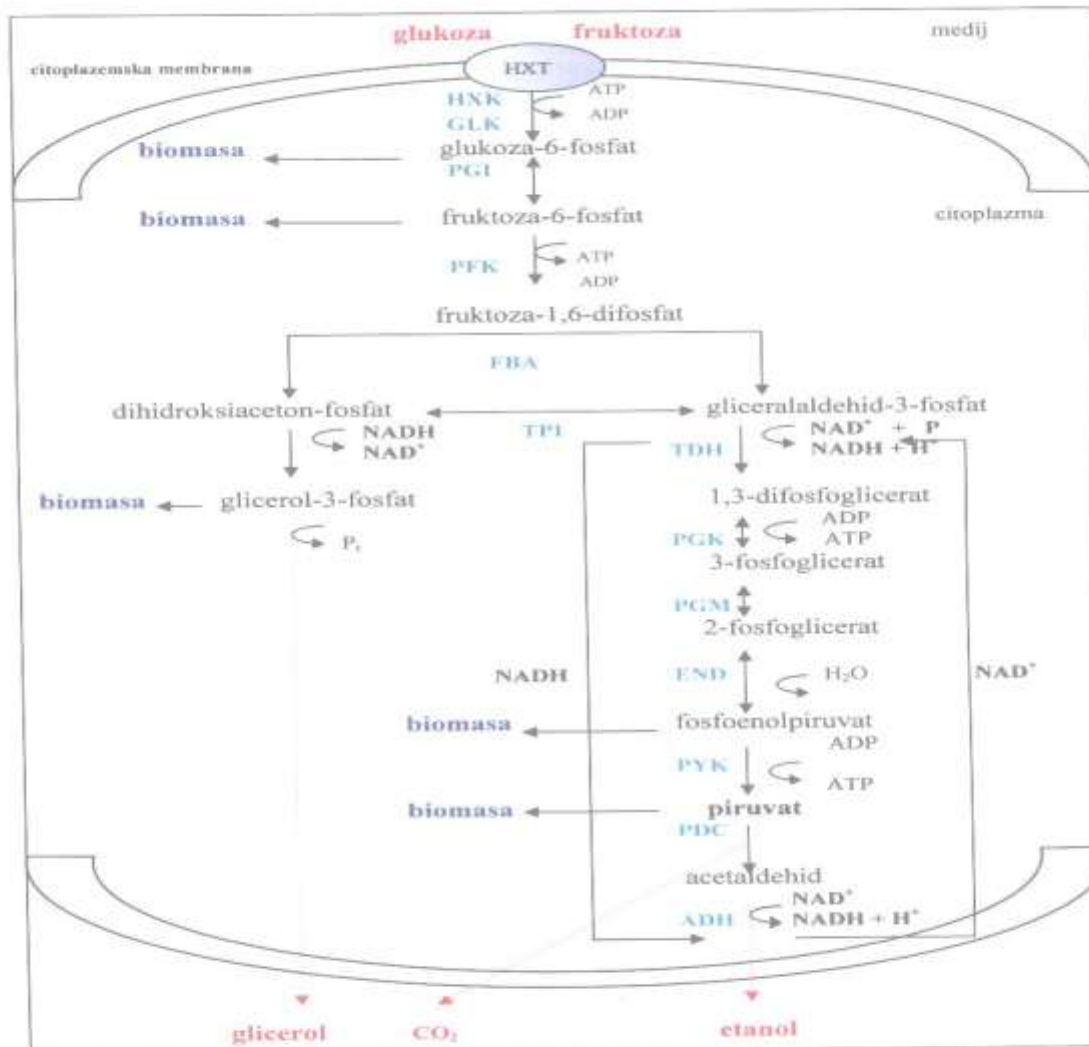




ZAKLJUČKI

- Statično magnetno polje ima pozitiven vpliv na metabolizem kvasovk
- Kvasovke, ki so bile izpostavljene magnetnemu polju, so bolj tolerantne na etanol
- Magnetnemu polju izpostavljene kvasovke so razgradile več sladkorjev v primerjavi s kontrolno kulturo
- Biomasa je hitreje naraščala pri kvasovkah, ki so bile izpostavljene magnetnemu polju

Glycolysis



Slika 5.: Shematični prikaz bioprocesa glikolize in alkoholne fermentacije.

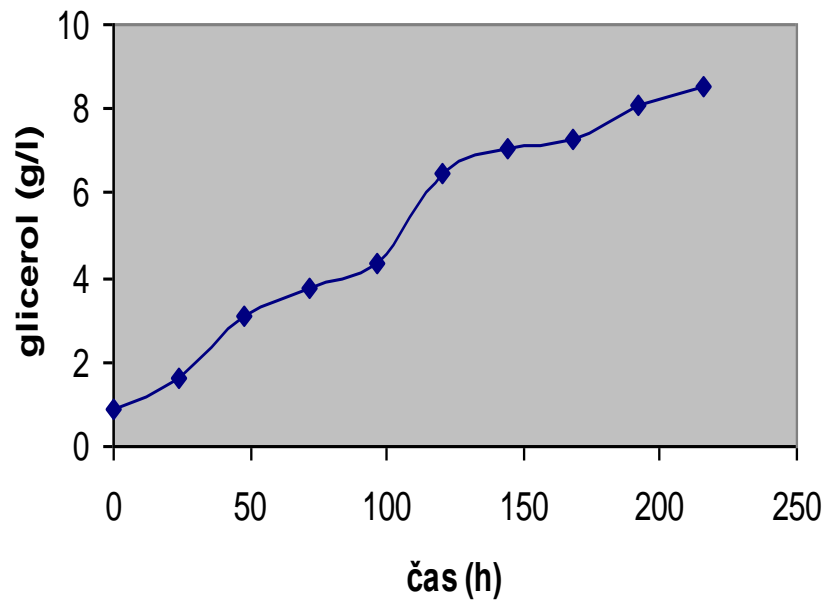
Pomen kratice na sliki: HXT (prenašalni protein za heksozo), HXK (heksokinaza), GLK (glukokinaza), PGI (fosfoglukoizomeraza), PFK (fosfofruktokinaza), FBA (aldolaza), TPI (triozafosfat izomeraza), TDH (gliceraldehid-3-fosfat dehidrogenaza), PGK (fosfoglicerat kinaza), PGM (fosfoglicerat mutaza), ENO (enolaza), PYK (piruvat kinaza), PDC (piruvat dekarboksilaza), ADH (alkohol dehidrogenaza), (Boulton *in sod.*, 1996)

Metabolizem kvasovk v alkoholni fermentaciji

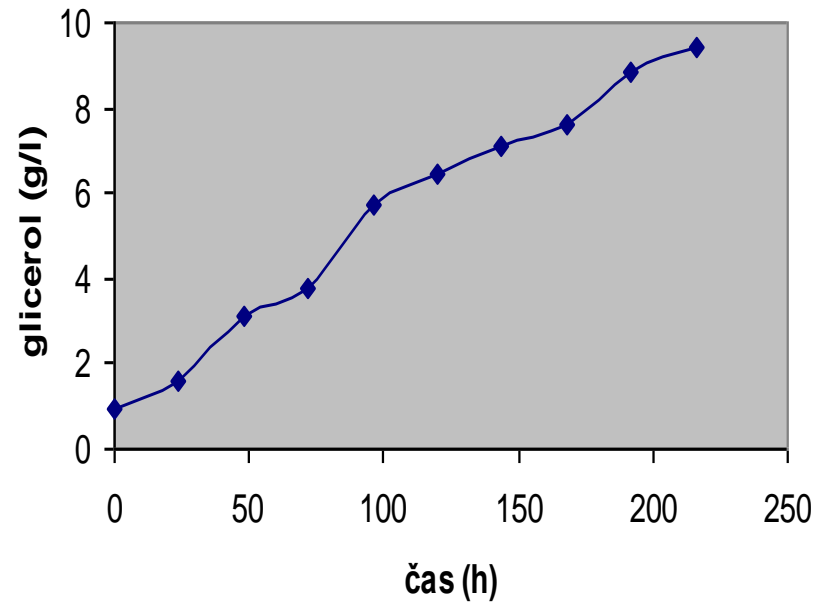


Nastajanje glicerola pri spreminjanju temperature fermentacije

Fermentacija z nihanjem temperature (18-22 st)



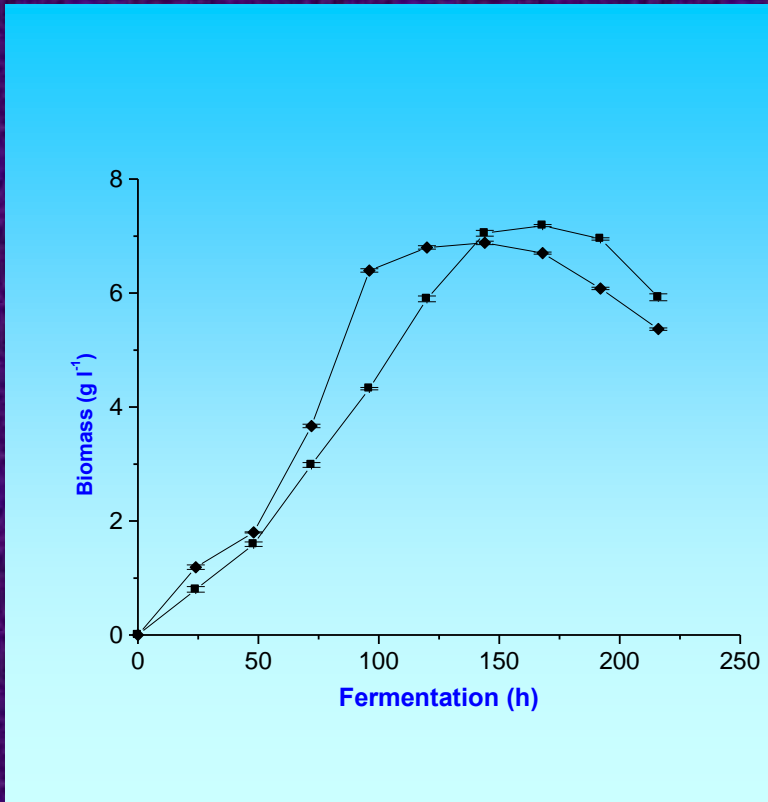
Fermentacija z nihanjem temp. (18-25 st)



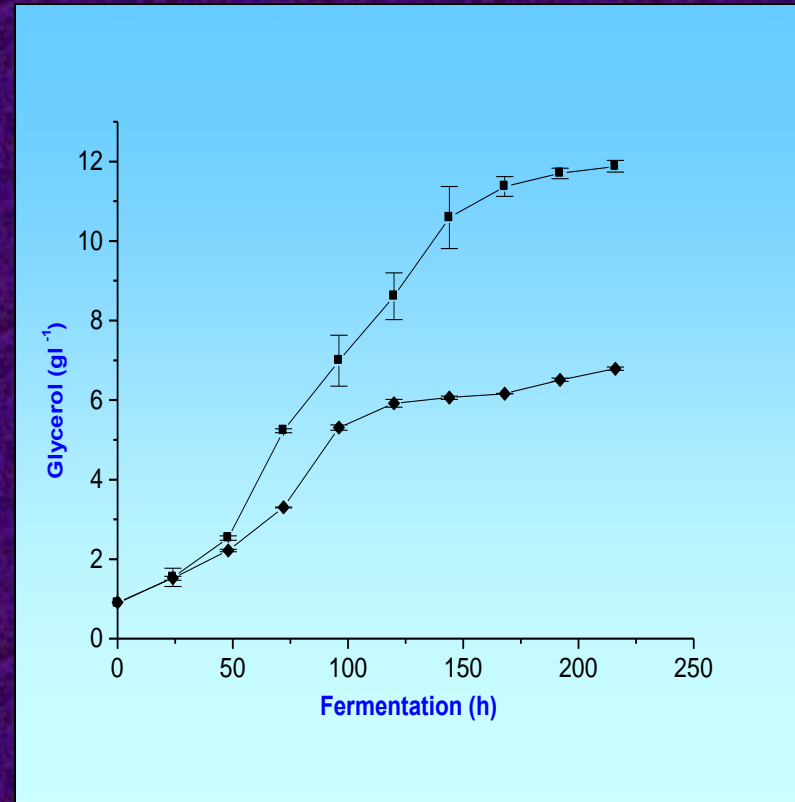
- S predhodnimi raziskavami smo ugotovili, da lahko produkcijo glicerola povečamo s spreminjanjem temperature med fermentacijo
- Pri temperaturnem šoku 45 °C, ki smo ga izvedli na vcepku pa smo dosegli enake koncentracije glicerola kot pri temperaturnih šokih pri 34 °C

| Ferm. | 18°C | T.Š. 8h/34°C | T.Š. 20min/45°C | 12h /18-25°C |
|-------------------|------|-----------------|--------------------|--------------|
| Glicerol (g/l) | 6,81 | 11,62 | 12,14 | 9,42 |

Vpliv temperaturnega šoka na vcepek *Sacharomyces cerevisiae*

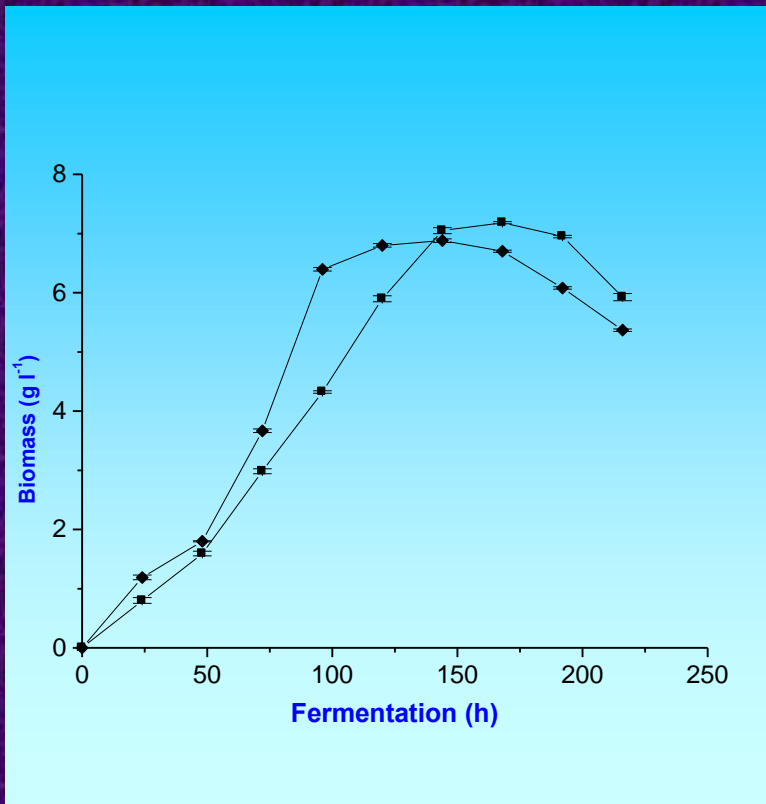


Slika 1. Biomasa v fermentaciji z ■ 20 minutnim temperaturnim šokom vcepka pri 45 °C in ♦ kontrolni vzorec pri fermentaciji pri 18 °C.



Slika 2. Produkcija glicerola v fermentaciji z ■ 20 minutnim temperaturnim šokom vcepka pri 45 °C in ♦ kontrolni vzorec pri fermentaciji pri 18 °C.

Vpliv temperaturnega šoka na vcepek *Sacharomyces cerevisiae*



Slika 1. Biomasa v fermentaciji z ■ 20 minutnim temperaturnim šokom vcepka pri 45 °C in ♦ kontrolni vzorec pri fermentaciji pri 18 °C.



Slika 2. Produkcija glicerola v fermentaciji z ■ 20 minutnim temperaturnim šokom vcepka pri 45 °C in ♦ kontrolni vzorec pri fermentaciji pri 18 °C.

Tabela 1. Metaboliti nastali med fermentacijo ob uporabi termično obdelanega vcepka v primerjavi s kontrolnim vzorcem.

| Metaboliti | Kontrolni vzorec (18 °C) (g l⁻¹) | Termično obdeleni vcepek (20 min / 45 °C) (g l⁻¹) |
|-------------------------|--|---|
| Biomasa | 6.7 ± 0.02 | 7.2 ± 0.02 |
| Red. sladkorji | 6.5 ± 0.23 | 2.4 ± 0.09 |
| Ocetna kislina | 0.28 ± 0.06 | 0.32 ± 0.02 |
| Jantarna kislina | 0.63 ± 0.11 | 0.75 ± 0.12 |
| Jabolčna kislina | 3.3 ± 0.16 | 3.4 ± 0.17 |
| Vinska kislina | 2.5 ± 0.18 | 2.2 ± 0.09 |
| Etanol | 84.70 ± 2.18 | 91.77 ± 0.93 |
| Glicerol | 6.81 ± 0,06 | 12.14 ± 0,26 |

Vpliv enojnih in dvojnih temperaturnih šokov na biosintezo glicerola

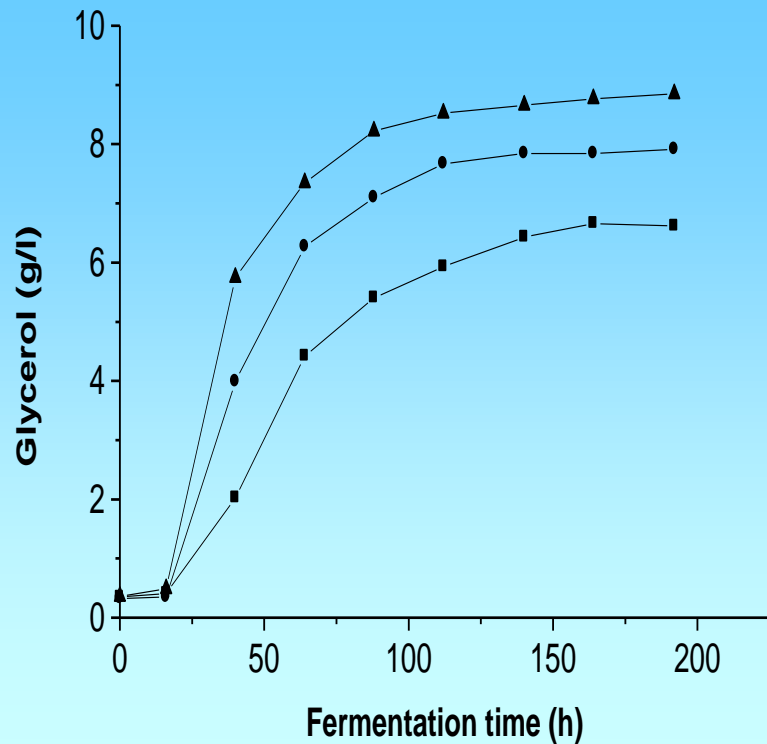


Fig. 1: Glycerol production at constant fermentation temperature of 18°C; black square, control; black circle, single heat shock at 34°C for 4 h; black triangle, single heat shock at 34°C for 24 h.

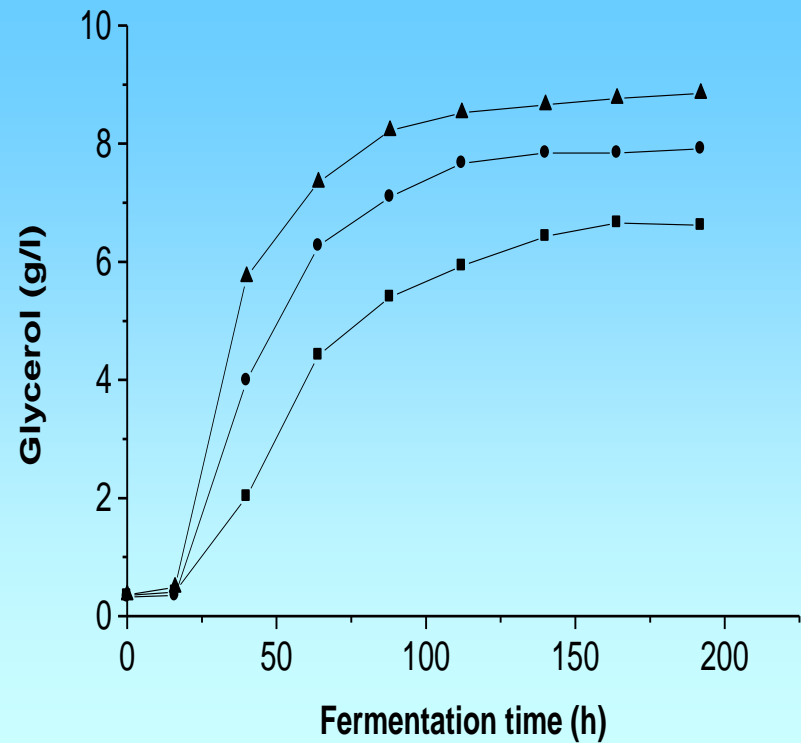


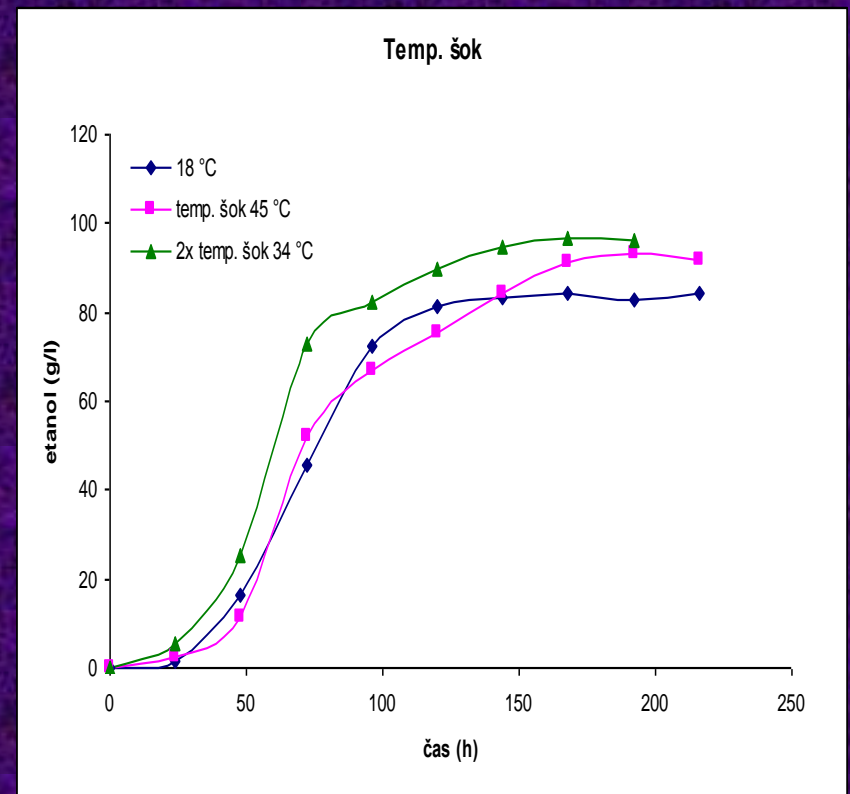
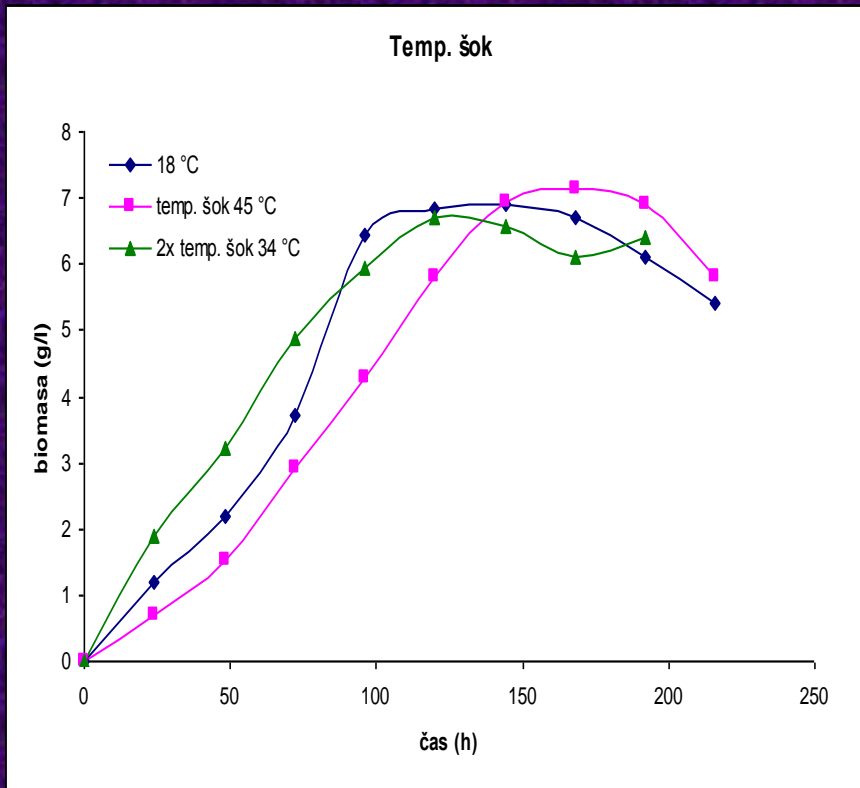
Fig. 2: Glycerol production at constant fermentation temperature of 18 °C; black square, control; black circle, double heat shock at 34°C (2 x 4 h); and black triangle, double heat shock at 34°C (2 x 8 h).

ZAKLJUČKI

- S temperaturnimi šoki smo dosegli večjo metabolno aktivnost vinskih kvasovk in s tem višjo produkcijo glicerola in višjih alkoholov
- Določili smo optimalni temperaturni šok pri 34°C, ki je bil pri 8-urah in dokazali da nihanje temperature 18-25°C pozitivno vpliva na produkcijo glicerola in višjih alkoholov
- Kvasovke ki preživijo temperaturni šok 45°C, ki smo ga izvedli na vcepku imajo povišano produkcijo glicerola tekom cele fermentacije. Ta metoda je zaradi tega zelo primerna za produkcijo vina v velikem merilu, saj s tem postopkom nimamo tehnoloških problemov s segrevanjem in ohlajanjem med fermentacijo, ter s hlapnimi aromami v vinu.

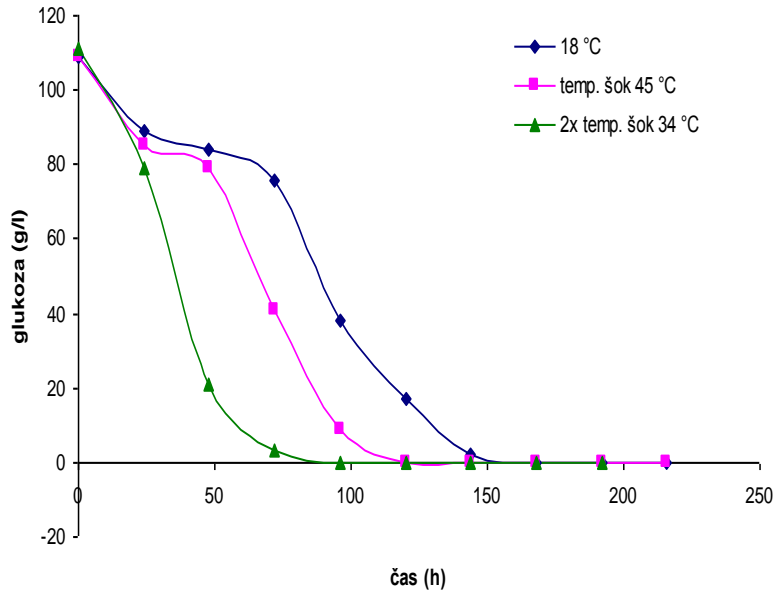
Rezultate raziskav smo objavili v člankih

- **Berovič M, Herga M. 2007 Heat shock on *Saccharomyces cerevisiae* inoculum increases glycerol production in wine fermentation *Biotechnol. Lett.* vol. 29, 6, 891-894 (2007)**
- **Berovič M, Pivec A., Košmerl T., Wondra M., Čelan Š., Heat Shock on Glycerol Production in Alcohol Fermentation. *J.Biosc.Bioeng.*vol.103,2,135-139 (2007)**

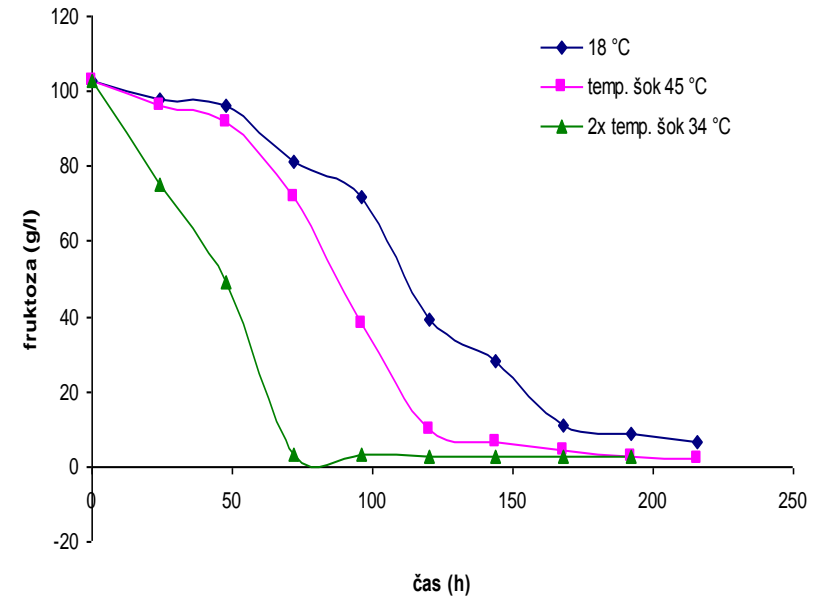


Naraščanje biomase in etanola med fermentacijo pri 18°C, 20 minutnem temperaturnem šoku na vcepku pri 45°C in dvakratnem 12 urnem temperaturnem šoku pri 34 °C

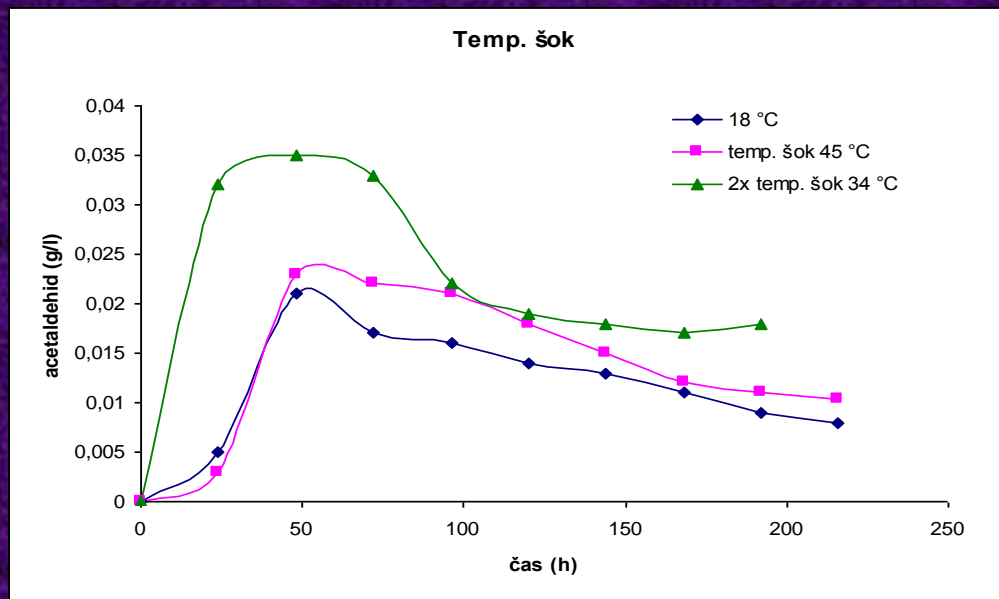
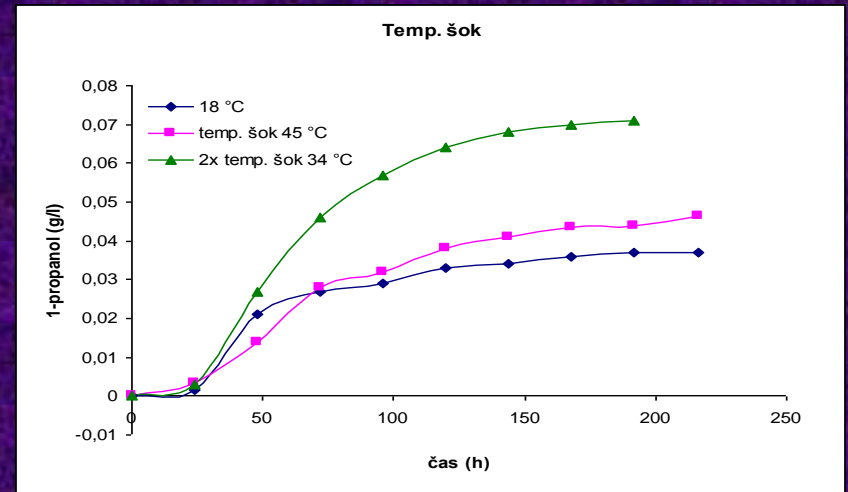
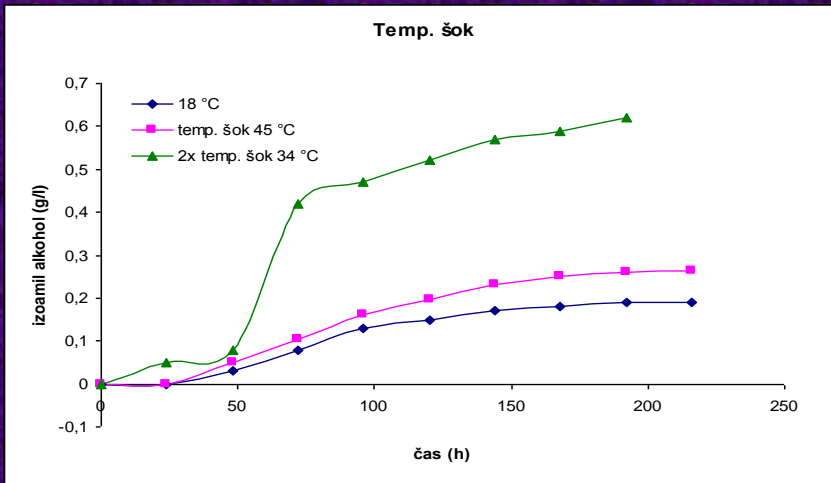
Temp. šok



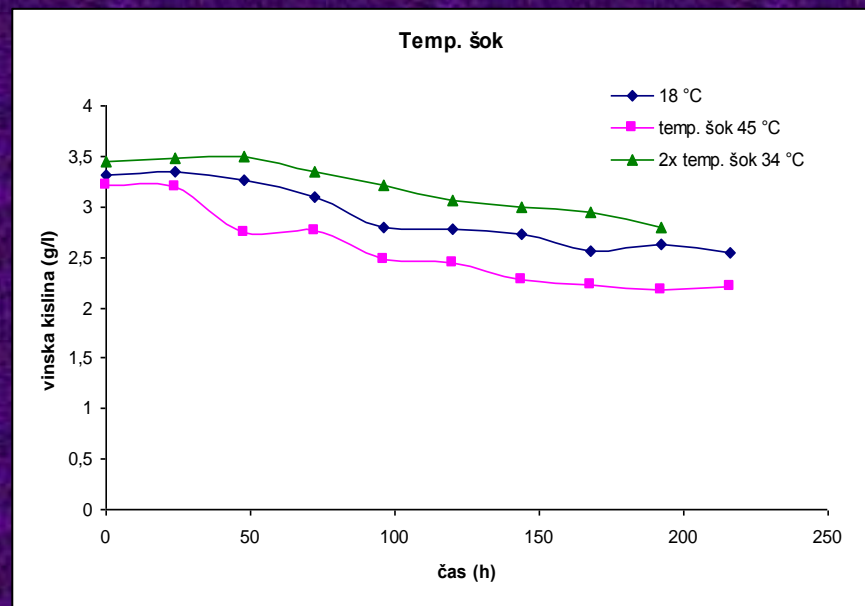
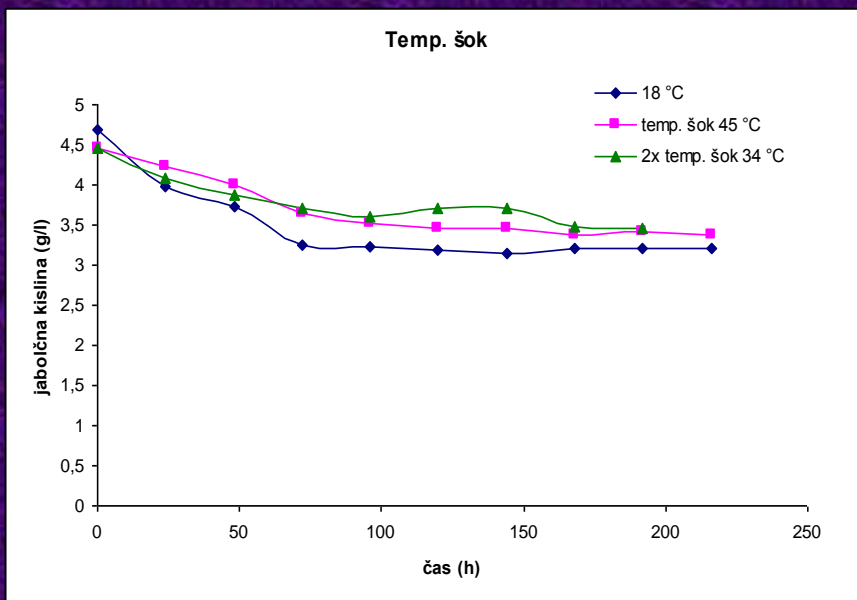
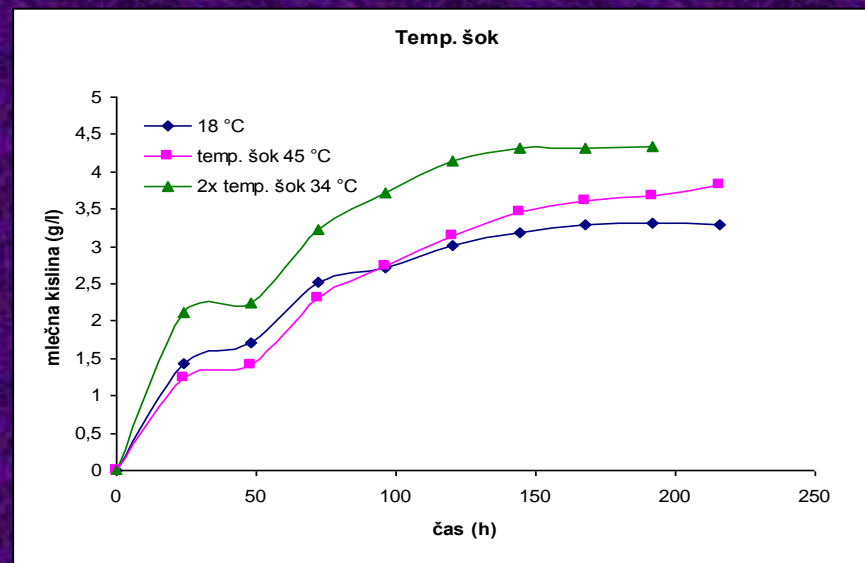
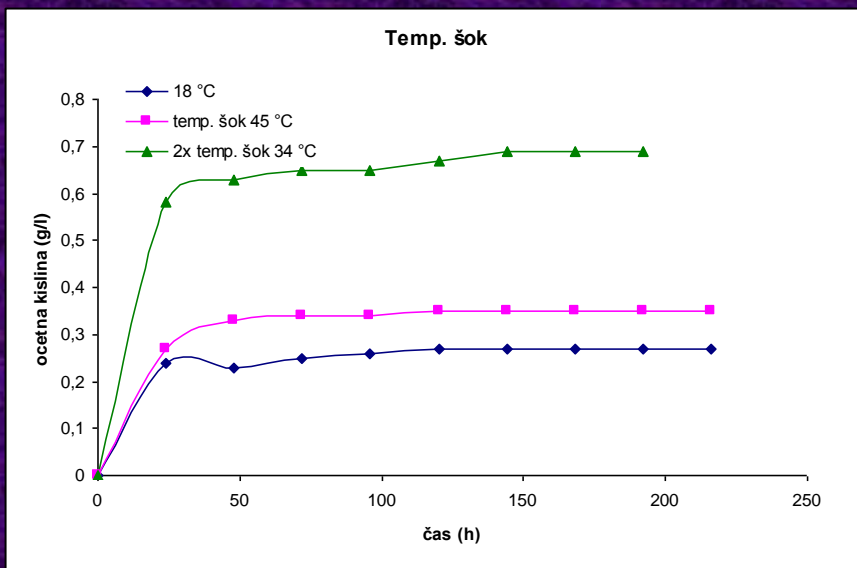
Temp. šok



Poraba glukoze in fruktoze med fermentacijo pri 18°C, 20 minutnem temperaturnem šoku na vcepku pri 45°C in dvakratnem 12 urnem temperaturnem šoku pri 34 °C



Nastajanje izoamilalkohola, 1-propanola in acetaldehida med fermentacijo pri 18°C, 20 minutnem temperaturnem šoku na vcepku pri 45°C in dvakratnem 12 urnem temperaturnem šoku pri 34 °C



Nastajanje očetne in mlečne kisline, upadanje vinske in jabolčne kisline med fermentacijo pri 18°C, 20 minutnem temperaturnem šoku na vcepku pri 45°C in dvakratnem 12 urnem temperaturnem šoku pri 34 °C

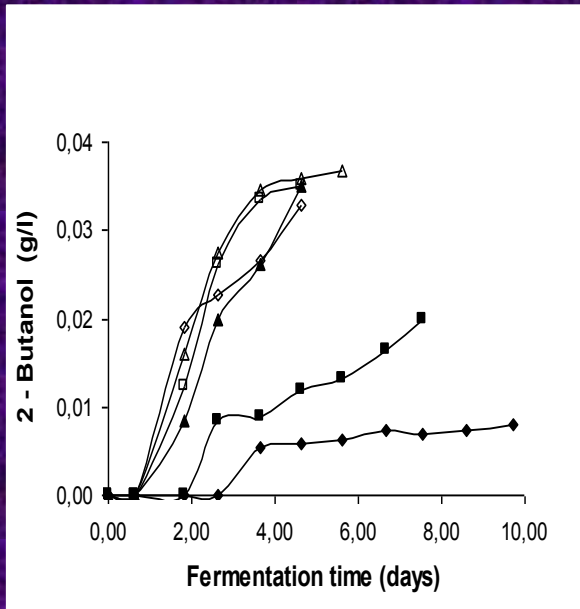
Table 1a,b: Metabolites produced in fermentations at various temperature conditions

Single HS: single heat shock for 4 h and single heat shock for 24 h

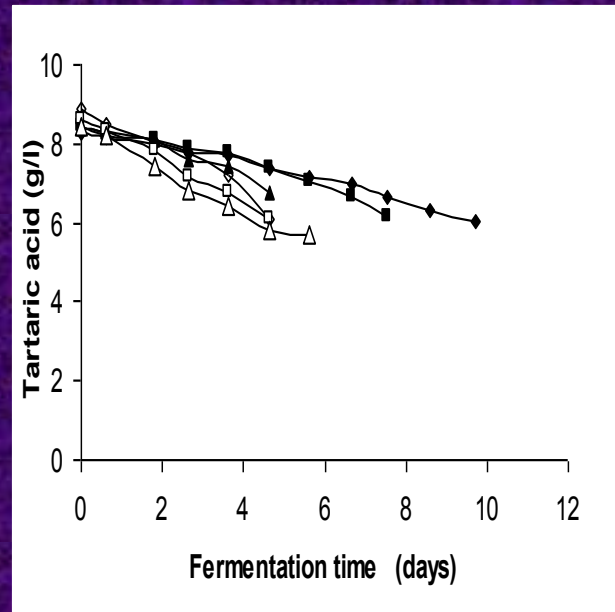
Double HS: double heat shock for 2 x 4 h and double heat shock for 2 x 8 h.

| Fermentation | Reduc. sugars (g l ⁻¹) | Isoamyl alcohol (g l ⁻¹) | 1-propanol (g l ⁻¹) | Acet aldehyde (g l ⁻¹) | Ethanol (g l ⁻¹) | E Glycerol (g l ⁻¹) | Acetic acid (g l ⁻¹) | Succ. acid (g l ⁻¹) | Citric acid (g l ⁻¹) | Malic acid (g l ⁻¹) | Tartaric acid (g l ⁻¹) |
|------------------|------------------------------------|--------------------------------------|---------------------------------|------------------------------------|------------------------------|---------------------------------|----------------------------------|---------------------------------|----------------------------------|---------------------------------|------------------------------------|
| Control (18°C) | 3.2 | 0.24 | 0.090 | 0.009 | 86.90 | 6.7 | 0.35 | 0.67 | 0.58 | 2.9 | 2.5 |
| Single HS (4h) | 2.6 | 0.33 | 0.031 | 0.010 | 92.00 | 7.9 | 0.45 | 0.73 | 0.57 | 2.5 | 3.5 |
| Single HS (24h) | 2.3 | 0.35 | 0.033 | 0.012 | 94.00 | 8.2 | 0.41 | 0.74 | 0.58 | 2.5 | 3.5 |
| Double HS (2x4h) | 2.0 | 0.51 | 0.037 | 0.013 | 101.00 | 10.0 | 0.56 | 0.78 | 0.72 | 2.3 | 3.6 |
| Double HS (2x8h) | 1.9 | 0.53 | 0.039 | 0.014 | 103.11 | 10.9 | 0.56 | 0.79 | 0.72 | 2.1 | 3.5 |

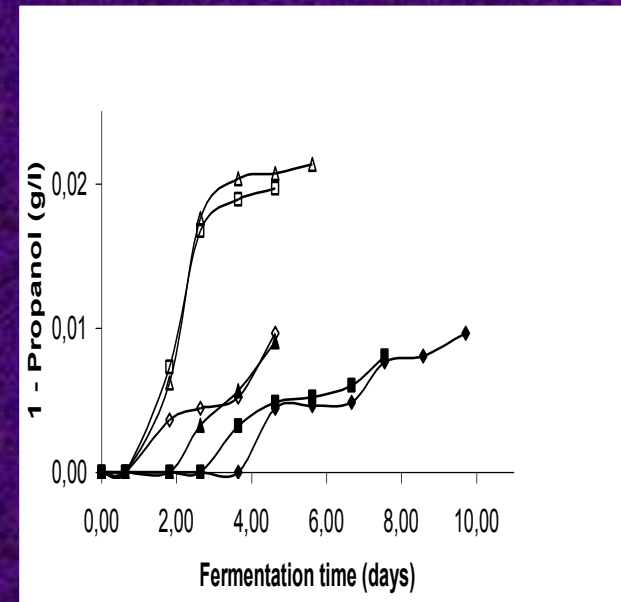
The Influence of Galvanic Field on *Saccharomyces cerevisiae* in Grape Must Fermentation



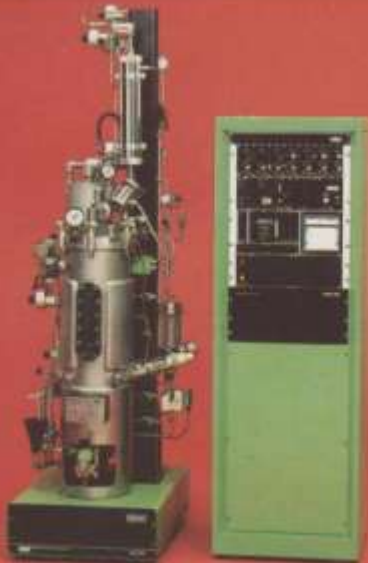
2-Butanol

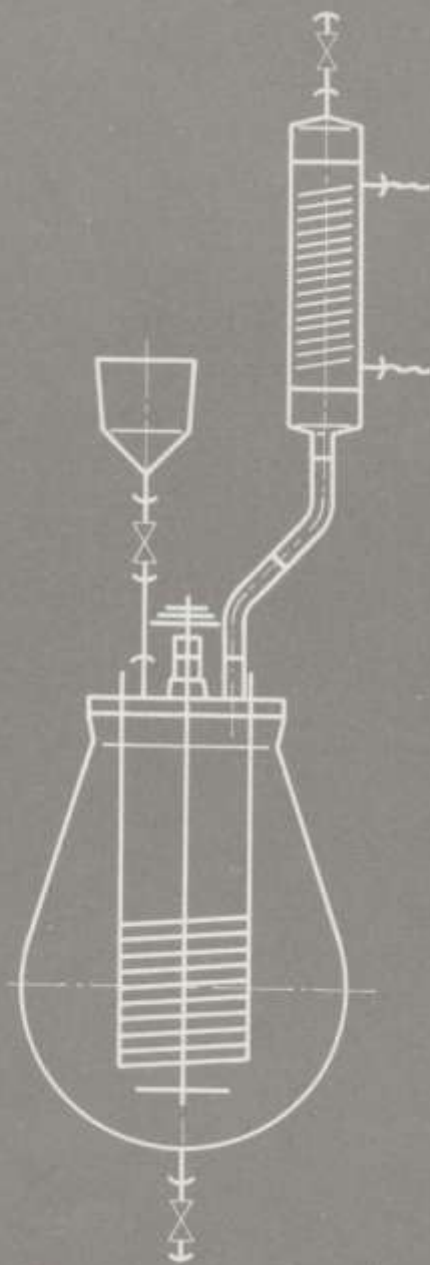


Tartaric acid

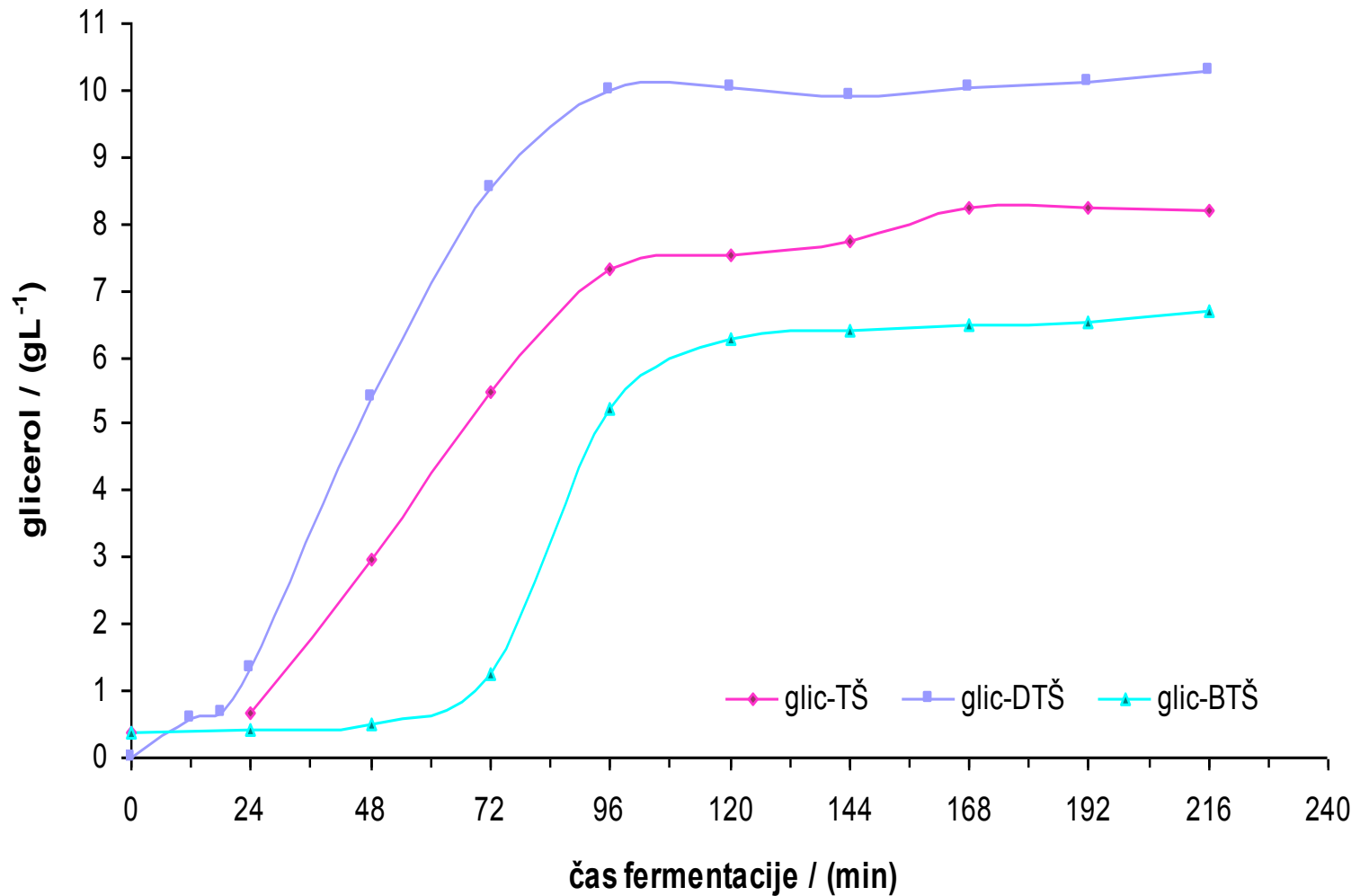


1-Propanol

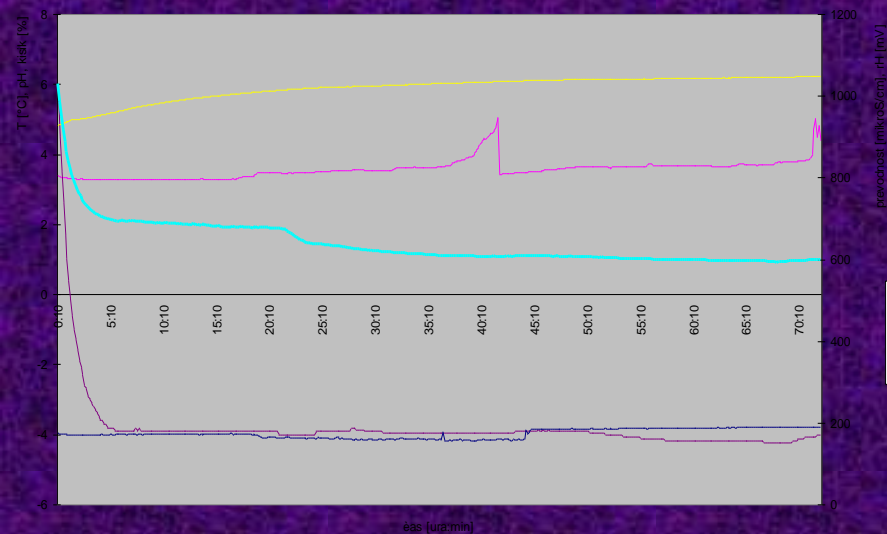




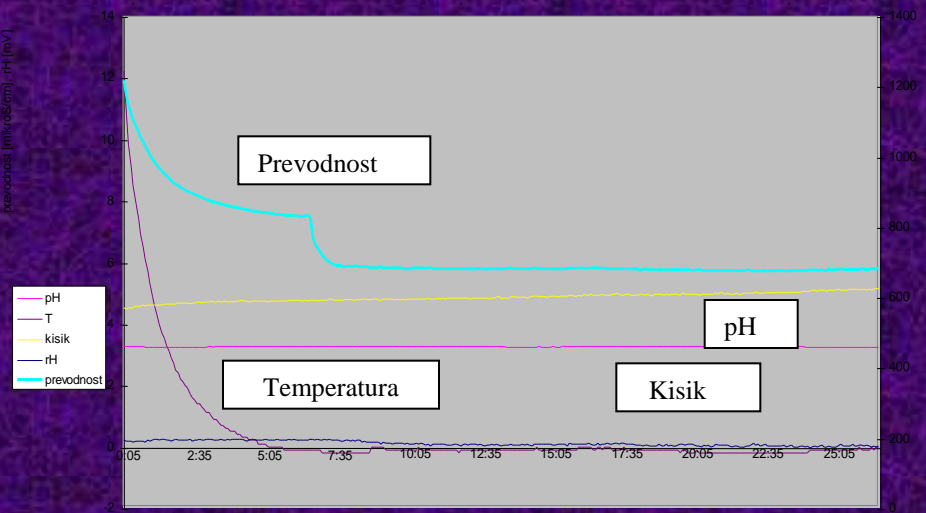
Produkcija glicerola v cv. Sauvignon



Ohlajevanje vina sorte *sauvignon* na 0°C ob kontroli procesa z merjenjem *on-line* prevodnosti

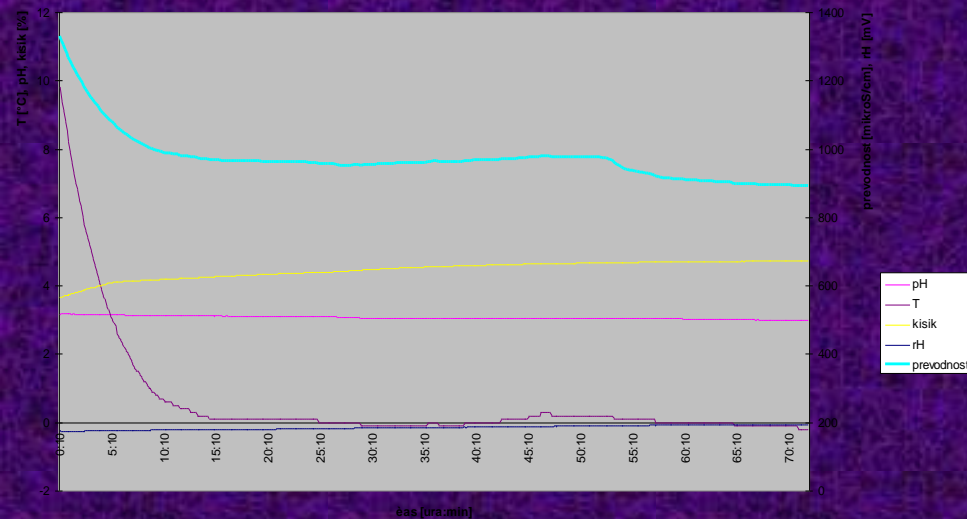


Hlajenje T=0 °C, čas termostiranja 72 ur

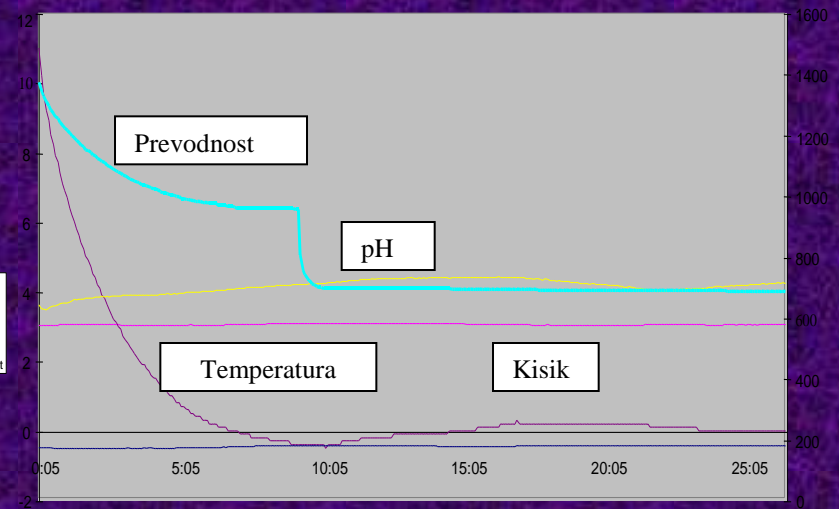


Ohlajevanje na 0°C ob dodatku 6g/l KHT
in ob kontroli procesa z merjenjem *on-line*
prevodnosti

Ohlajevanje vina sorte *sauvignon* na 0°C ob kontroli procesa z merjenjem *on-line* prevodnosti



Hlajenje T=0 °C, čas termostiranja 72 ur



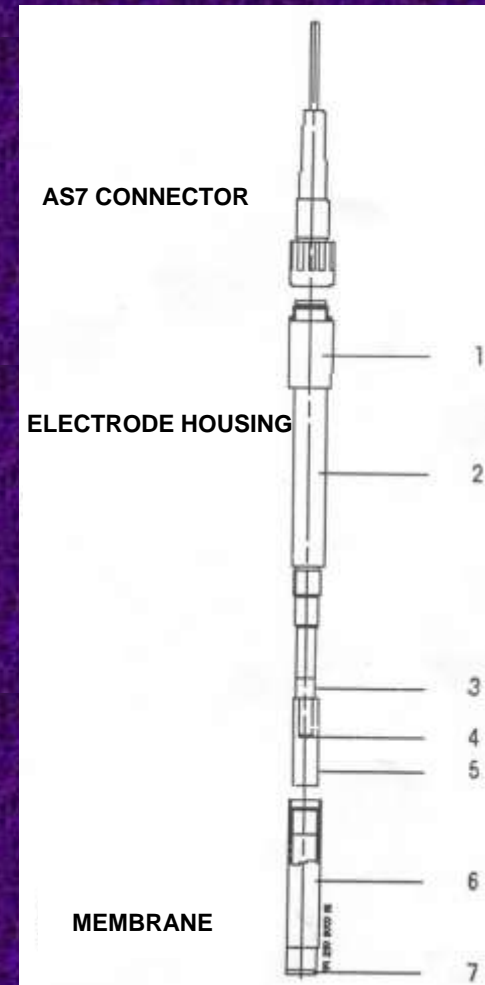
Ohlajevanje na 0°C ob dodatku 6g/l
KHT in ob kontroli procesa z
merjenjem *on-line* prevodnosti

Nastali produkti ob uporabi temperaturnih šokov

| | <i>BTŠ</i> | <i>TŠ</i> | <i>DTŠ</i> |
|--|-----------------------|-----------------------|------------------------|
| reducirajoči sladkorji | 4,4 gL ⁻¹ | 2,6 gL ⁻¹ | 2,0 gL ⁻¹ |
| glicerol | 6,65 gL ⁻¹ | 7,5 gL ⁻¹ | 10,5 gL ⁻¹ |
| etanol | 86,9 gL ⁻¹ | 92,8 gL ⁻¹ | 101,1 gL ⁻¹ |
| čas trajanja alkoholne fermentacije | 156 ur | 144 ur | 120 ur |
| Glicerol : etanol | 7,65 % | 8,08 % | 10,39 % |
| izoamilalkohol | 240 mgL ⁻¹ | 330 mgL ⁻¹ | 500 mgL ⁻¹ |
| 1-propanol | 10 mgL ⁻¹ | 30 mgL ⁻¹ | 37 mgL ⁻¹ |
| acetaldehid | 17 mgL ⁻¹ | 10 mgL ⁻¹ | 13 mgL ⁻¹ |

Sensor for SO₂ measurement

on-line measurement of free SO₂
with
modified CO₂ electrode



Potentiometric CO₂ electrode

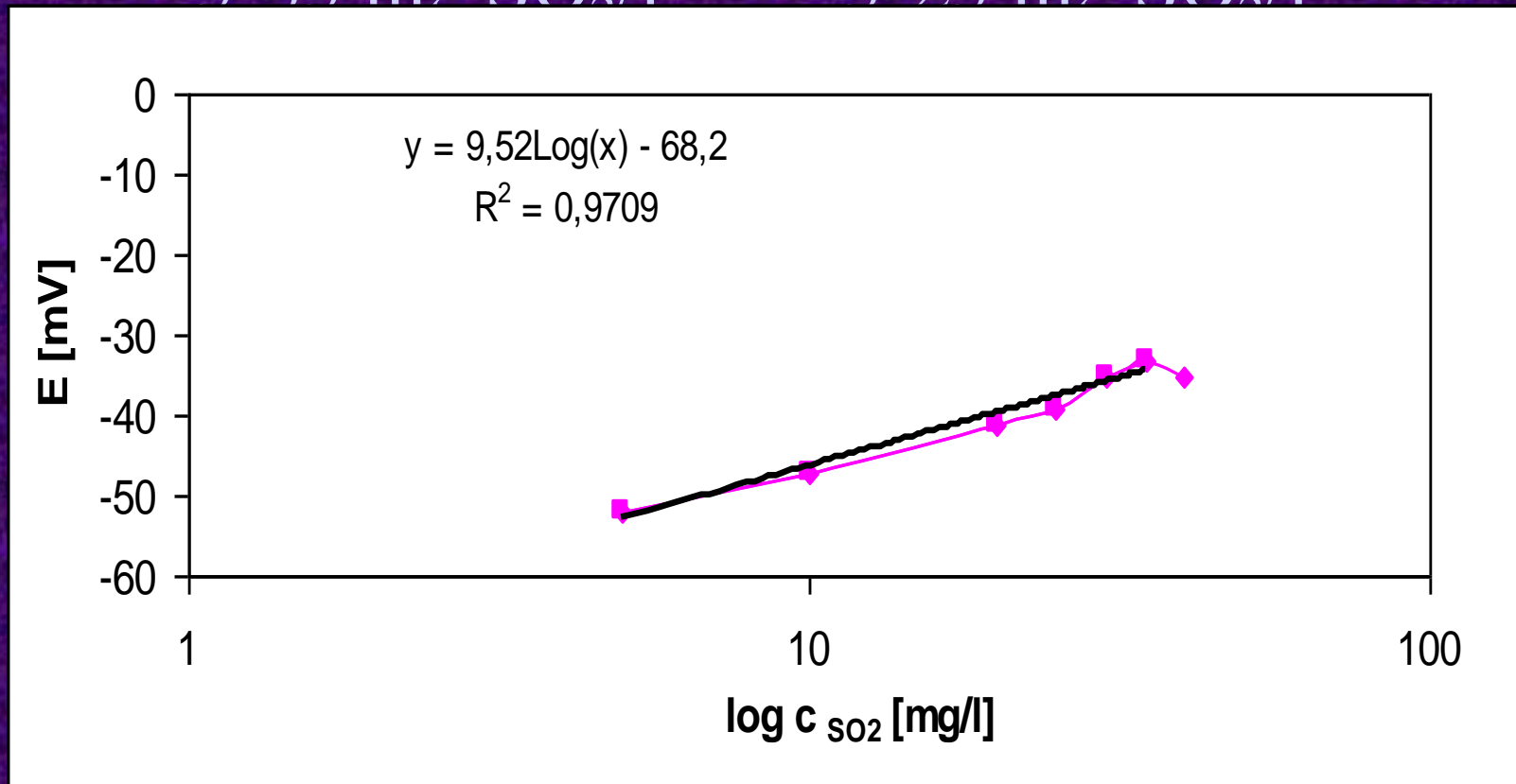
Free SO₂ measurement

→ Red wines

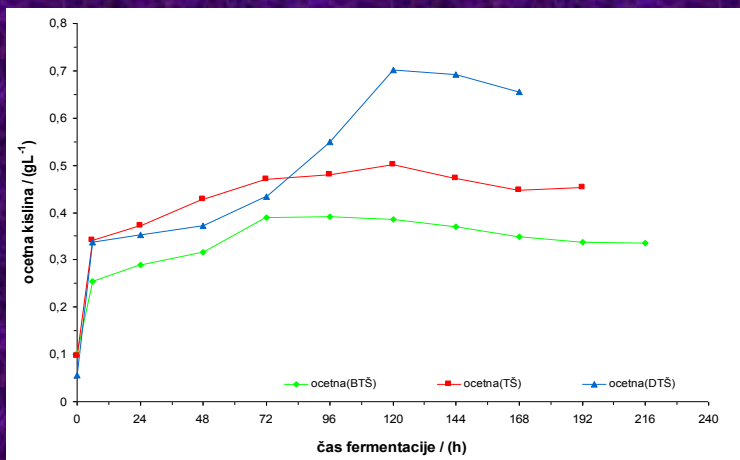
→ White wines

5-35 mg SO₂/l

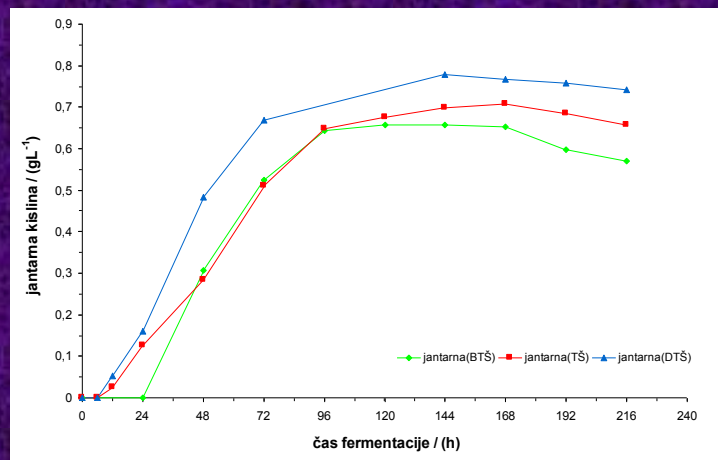
5-25 mg SO₂/l



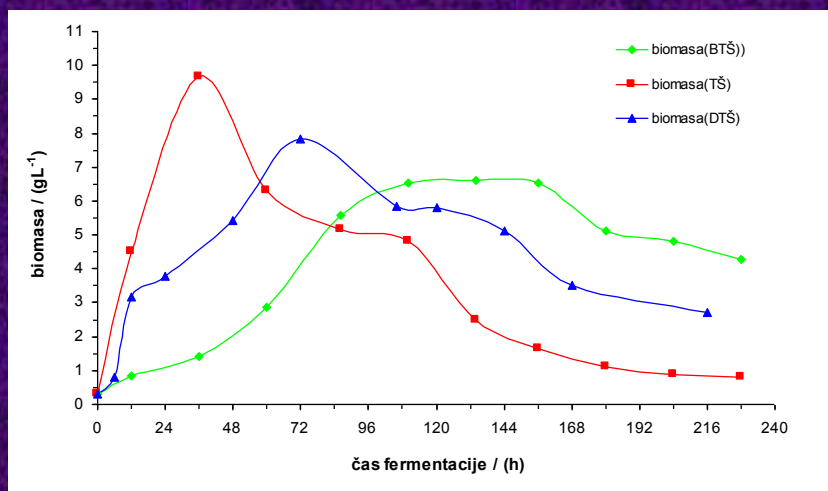
Nastali produkti ob uporabi temperaturnih šokov



Nastanek ocetne kisline pri konstantni temperaturi 18 °C (BTŠ), pri fermentaciji z enim temperaturnim šokom (TŠ) in z dvema temperaturnima šokoma (DTŠ)



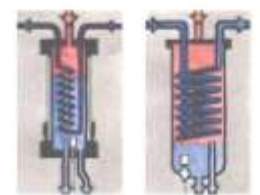
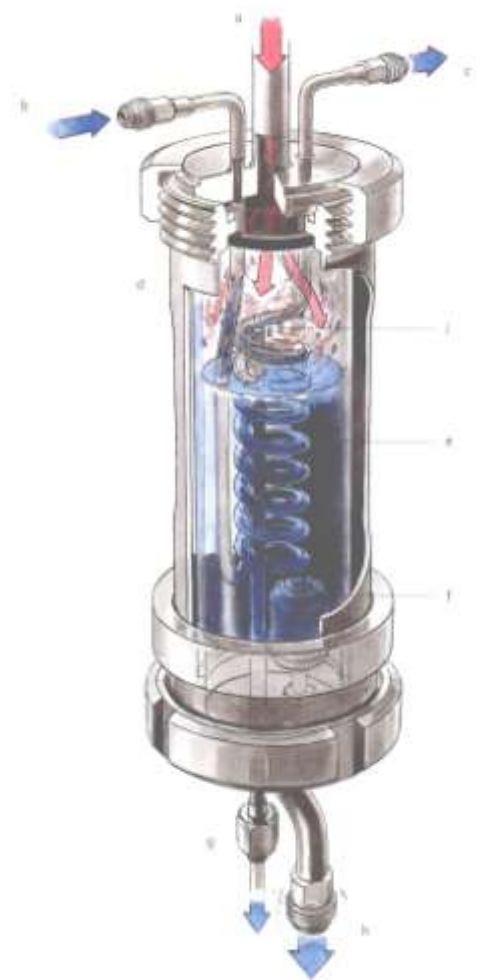
Nastanek jantarne kisline pri konstantni temperaturi 18 °C (BTŠ), pri fermentaciji z enim temperaturnim šokom (TŠ) in z dvema temperaturnima šokoma (DTŠ)



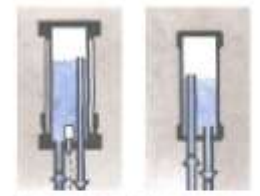
Rast biomase pri fermentacijah brez temperaturnega šoka (BTŠ), z enim temperaturnim šokom (TŠ) in z dvema temperaturnima šokoma (DTŠ).

on-line meritev SO₂, vpliv galvanskega polja,
povišanje produkcije glicerola
in kontrola kristalizacija z merjenjem konduktivnosti
s precipitacijo in sočasnim ohlajanjem

Marin BEROVIČ – FKKT Ljubljana
Aleksandra PIVEC – ZRS Bistra Ptuj
Tatjana KOŠMERL – BF Ljubljana
Mojmir WONDRA – BF Ljubljana
Andrej HOLOBAR – ECHO Sl.Konjice
Keith Racman – Mettler Toledo
Mateja Potočnik – FKKT Ljubljana
Jasna Štrus – BF Ljubljana
Štefan ČELAN – ZRS Bistra Ptuj



Pressurized condensate vessel.
 Left: sight glass design, right: steel vessel. Both with float switch.



Non-pressurized balancing vessel,
 with and without float switch.
 Manual refilling.



