Yeast–Yeast Interactions: Mechanisms, Methodologies and Impact on Composition

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Table S1: Diversity of methodologies and results in yeast interaction experiments

Species		*Saccharomyces cerevisiae / Metschnikowia pulcherrima*								
Matrix		**Synthetic Medium**						**Grape Juice / Must (unspecified color)**		
		SGJ	SGJ				SGJ	Grape must		
Sugar Initial Concentration (g/L)		200 (Glc 100 Fru 100)	200 (Glc 100 Fru 100)				200 (Glc 100 Fru 100)	231		
YAN / PAN (mg/L)		YAN 410					200	PAN 154 / NH_3 22		
Temperature (°C)		25	25				20	25		
Oxygenation		++	-	+	++	+++	+	+		
Inoculation delay between 2 strains (h)		0	0				0	0		
Ratio Sc/NS		1:1	1:10				1:10	1:1	1:100	1:10000
Sc population	**Max**	1	3	3	3	3	4	3	2	3
	Dominance		+					2	2	2
	Decrease	-	-	+	+	+	+	-	-	-
NS population	**Max**	1	1	1	1	1	1	7	1	3
	Decrease	2 or 1	1	3	3	3	-	7	3	3
	Detectable End	No 2 or 4						No 22	No 7	No 7
Fermentation completion							+	+	+	+
Ethanol		=	=	- -	- -	- -	-	- -	- -	- -
Glycerol			++	- -	- -	- -	+	++	++	++
Organic acids	**TA**							- -	- -	- -
	VA							- -	- -	- -
	LA									
	AA									
Impacting Factors		SPE / NS	OX / SPE				SPE	RAT / SPE		
Interaction Mechanisms		TOX	COMP				COMP / TOX			
Reference		[65]	[29]				[95]	[32]		

Species		*Saccharomyces cerevisiae / Metschnikowia pulcherrima*											
Matrix		Red Grape Juice / Must					White Grape Juice / Must						
		Shiraz	Merlot	Shiraz	Tempranillo	Pinot Grigio	Sauvignon blanc	Riesling	Sauvignon blanc	Chardonnay	Muscat commercial grape juice	Sauvignon blanc	Riesling
Sugar Initial Concentration (g/L)		210	240	280 (Glc 140 Fru 140)	245	236	219 (Glc 110 Fru 109)	237	217	240 (Glc 120 Fru 120)	200 (supp)	221 (Glc 112 Fru 109)	225
YAN / PAN (mg/L)		200	190	YAN 170 (supp)	YAN 181	YAN 236	YAN 588	PAN 147	YAN 170 (supp)	260		YAN 378	YAN 250 (supp)
Temperature (°C)		22	22	25		22	20	20	15	22	20	20	20
Oxygenation		+	++	++	+	+	+	+	+	+	+	+	+
Inoculation delay between 2 strains (h)		24 days	0	96	72	48	48	24	168	24 days	72	48	48
Ratio Sc/NS		1:1	1:10	1:1	1:1	1:1	1:10	10:1	1:1	1:1	1:5	1:10	1:1
Sc population	**Max**							4			5	3	4
	Dominance		+	+									
	Decrease		-				-	-			-	-	-
NS population	**Max**												0
	Decrease	+	2	+	+		+	+	+	15	5	4	2
	Detectable End			No 7	No 4-5		No 8	No 15	No 12	No 25	Low 13	No 8	4
Fermentation completion		+		17		9	8	+	19	40	10	10	+
Ethanol		- -	-	=	- -	-	-	- -	=	-		-	=
Glycerol		-	++		++	++		++		+		++	++
Organic acids	**TA**						- -		+				- -
	VA	+		=	- -				++	++			
	LA												
	AA	- -	=			=	- -	=	++	- -		- -	=
Impacting Factors		GRA		SPE	SPE	SPE / NS	SPE	SPE	SPE	GRA	SPE / TEMP / DEL / MED	DEL	DEL
Interaction Mechanisms											COMP	COMP	
Reference		[155]	[153]	[36]	[37]	[14]	[47]	[38]	[41]	[155]	[55]	[87]	[44]

Species		*Saccharomyces cerevisiae / Starmerella bacillaris*									
Matrix		**Synthetic Medium**	**Grape Juice / Must (unspecified color)**			**White Grape Juice / Must**					
		SGJ	Grape must			Macabeo	Erbaluce / dried grape must		Sauvignon blanc	Sauvignon blanc	Muscat (commercial grape juice)	Chardonnay / Muscat / Riesling / Sauvignon blanc
Sugar Initial Concentration (g/L)		200 (Glc 100 Fru 100)	231			180	403 (Glc 210 Fru 193)		219 (Glc 110 Fru 109)	217	200 (supp)	245
YAN / PAN (mg/L)		YAN 410	PAN 154 / NH_3 22			YAN 115			YAN 588	YAN 170 (supp)		YAN 180 adj
Temperature (°C)		25	25			20	25		20	15	20 / 28	20
Oxygenation		++	+			+	+		+	+	+	+
Inoculation delay between 2 strains (h)		0	0			0	0	48	24	144	72	48
Ratio Sc/NS		1:1	1:1	1:100	1:10000	1:9	1:1		1:10	1:1	1:5	1:1
Sc population	**Max**		2	2	10				3		=	
	Dominance	-	-	-	-	-	-	-	-		-	=
	Decrease		1	3	10	- +						-
NS population	**Max**		1	2	2				1			
	Decrease	4	7	10	15	+	6	6/12	-	+	-	7
	Detectable End	No 5 / Yes	No 15	No 22	No 22	Low 10				No 14		No 14
Fermentation completion			+	+	+	10			7	24		14
Ethanol			- -	- -	- -		- -	- -	-	=	=	-
Glycerol			++	++	++	++	++	++				++
Organic acids	**TA**		- -	- -	- -				+			++
	VA		- -	- -	- -							
	LA											
	AA					++	= / - -	= / - -		++		
Impacting Factors		SPE / NS	RAT / SPE			SPE	DEL / SC / NS		SPE	SPE	SPE / TEMP / DEL / MED	GRA / TEMP
Interaction Mechanisms		TOX				COMP					COMP	
Reference		[65]	[32]			[48]	[23]		[47]	[41]	[55]	[79]

Species		*Saccharomyces cerevisiae / Starmerella bacillaris*																
		Red Grape Juice / Must																
Matrix		Merlot			Barbera		Shiraz	Barbera		Cabernet sauvignon / Merlot / Pinot noir / Shiraz		Kotsifali - Manilari 3:1				Barbera	Nebbiolo	Pinot Grigio
Sugar Initial Concentration (g/L)		240			244		280 (Glc 140 Fru 140)	246		250		220		214		234 (Glu 118 Fru 116)	234 (Glu 115 Fru 120)	236
YAN / PAN (mg/L)							YAN 170 (supp)	YAN 180 adj		YAN 180 adj		YAN 240		YAN 71 + suppl		YAN 180 adj	YAN 180 adj	YAN 236
Temperature (°C)		24			25		25	25		25		25		25		25	25	22
Oxygenation		+			+		++	+	++	+		+		+		+	+	+
Inoculation delay between 2 strains (h)		0	24	48	0	48	96	48		24	48	0	30	0	30	48	48	48
Ratio Sc/NS		1:5			1:1		1:1	1:1		1:1		1:1				1:1	1:1	1:1
Sc population	**Max**																	
	Dominance				-	-				= / +	-	+	-			-	-	
	Decrease						+	-	-	-	-		-	-	-	10	-	+
NS population	**Max**				4													
	Decrease					+	+	4	4	4	4/7	3	8	2	2	7	7	+
	Detectable End				No 21	Yes 21	No 7	No 14 / 21	No 14 / Yes 21			Low 5		Low 6	Low 7	No 10 / 14	No 9 / Yes 14	Low 5
Fermentation completion		+	+	+	-	-	17	+ / -	+ / -	7	7/10	6	13			14	14	14
Ethanol		=	- -	- -	- -	- -	=	- -	- -	- -		-	- -	- -	- -	- - / =	= / - -	-
Glycerol			++	++	=	++		++	++	++		=	++	++	++	++	++	++
Organic acids	**TA**		++	++						++		=	++			++		
	VA						++						++		=			
	LA																	
	AA							++	+++				++	=	=	- -		
Impacting Factors		NS / DEL			DEL / NS / SC		SPE	OX / NS / SC		DEL / GRA		DEL				SC		SPE / NS
Interaction Mechanisms								COMP				TOX / COMP					Not TOX / Not COMP / CCC	
Reference		[75]			[12]		[36]	[67]		[60]		[49]				[69]	[68]	[14]

Species		***Saccharomyces cerevisiae* / *Torulaspora delbrueckii***														
Matrix		**Synthetic Medium**														
		SGJ	WYPD		SGJ	SGJ				SGJ				SGJ	SGJ	
Sugar Initial Concentration (g/L)		210 (Glc)	200 (Glc)		210 (Glc)	220 (Glc 110 Fru 110)				200 (Glc 100 Fru 100)				200 (Glc 100 Fru 100)	200 (Glc 100 Fru 100)	
YAN / PAN (mg/L)						YAN 324		YAN 176						YAN 410	200	
Temperature (°C)		25	25		25	20				25				25	20	
Oxygenation		+	++	+	+	+				-	+	++	+++	++	+	
Inoculation delay between 2 strains (h)		0	0		0	0	0	48	48	0				0	0	
Ratio Sc/NS		1:1	1:1		1:1	1:2	1:20	1:2	1:2	1:10				1:1	1:10	
Sc population	**Max**	2	1	1	2	2	2	4	5	3	3	3	3	1/3	2	
	Dominance	+	+	+	+											
	Decrease	-	-	-	-	-	-	-	-	-	+	+	+	-	-	
NS population	**Max**	2	1	1	1	2	3	3	2	1	1	1	1	1	2	
	Decrease	3	-	-	3	3	4	4	2	1	3	3	3	2/3	-	
	Detectable End	Low 7			Low 6	Low 5								No 6 / Yes		
Fermentation completion		10			10	7	5	9								
Ethanol						=	=	-	=	=	- -	- -	- -	=	- -	
Glycerol										++	- -	- -	- -		=	
Organic acids	**TA**															
	VA															
	LA															
	AA					=	=	- -								
Impacting Factors						RAT / DEL				OX / SPE				SPE / NS	SPE	
Interaction Mechanisms		Not TOX / Not COMP / CCC	Not TOX / Not COMP / Not QS / CCC		COMP	Not CCC / Not COMP / TOX				COMP				TOX	COMP / TOX	
Reference		[25]	[26]		[27]	[51]				[29]				[65]	[95]	

Species		*Saccharomyces cerevisiae / Torulaspora delbrueckii*							
Matrix		**Grape Juice / Must (unspecified color)**			**White Grape Juice / Must**			**Red Grape Juice / Must**	
		Grape must			Sauvignon blanc	Sauvignon blanc	Riesling	Shiraz	Tempranillo
Sugar Initial Concentration (g/L)		231			219 (Glc 110 Fru 109)	217	225	280 (Glc 140 Fru 140)	245
YAN / PAN (mg/L)		PAN 154 / NH_3 22			YAN 588	YAN 170 (supp)	YAN 250 (supp)	YAN 170 (supp)	YAN 181
Temperature (°C)		25			20	15	20	25	
Oxygenation		+			+	+	+	++	+
Inoculation delay between 2 strains (h)		0			24	120	48	96	72
Ratio Sc/NS		1:1	1:100	1:10000	1:10	1:1	1:1	1:1	1:1
Sc population	**Max**	3	10	3	3		4		
	Dominance	2		15				+	
	Decrease	-	-	-	-		15		
NS population	**Max**	3	3	3	1		0		
	Decrease	3	10	15	-	+	4	+	+
	Detectable End	No 15	No 22	No 22		14	No 6	No 7	Yes 6
Fermentation completion		+	+	+	7	19	+	17	
Ethanol		- -	- -	- -	-	=	=	=	- -
Glycerol		- -	- -	- -			++		++
Organic acids	**TA**	+	+	+	+	=	- -		
	VA	- -	- -	- -	- -	=		=	- -
	LA								
	AA					-	=		
Impacting Factors		RAT / SPE			SPE	SPE	DEL	SPE	SPE
Interaction Mechanisms									
Reference		[32]			[47]	[41]	[44]	[36]	[37]

Species		***Saccharomyces cerevisiae* / *Hanseniaspora guilliermondii***									
Matrix		**Synthetic Medium**								**White Grape Juice / Must**	
		SGJ						SGJ	SGJ	Malvasia fina - Arinto	Malvasia fina - Arinto
Sugar Initial Concentration (g/L)		200 (Glc 110 Fru 110)					100	220 (Glc 110 Fru 110)	220 (Glc 110 Fru 110)	234	234
YAN / PAN (mg/L)										YAN 175 / 387 (supp)	YAN 387
Temperature (°C)		18						20	25	20	20
Oxygenation		+						+	+	+	+
Inoculation delay between 2 strains (h)		0						0	0	0	0
Ratio Sc/NS		1:1	3:1	1:2	1:10	1:100	1:10	1:1	1:1	1:1	1:1
Sc population	**Max**	2	3	7	7	7			2	1	1
	Dominance										-
	Decrease	-	-	-	-	-		-	-	-	-
NS population	**Max**	1			3	3			2	1	1
	Decrease	1	+	1	4	15	7	+	2	2	6
	Detectable End	No 7	No 3	No 8	No 11	No 23	Yes 34	Low 4	No 4	No 12	Low 10
Fermentation completion		20	20	25	25	25		+	9	+	
Ethanol										-	
Glycerol											
Organic acids	**TA**									=	
	VA									=	
	LA									=	
	AA									=	
Impacting Factors		RAT								MED	
Interaction Mechanisms		TOX / Not COMP						TOX		Not COMP	
Reference		[52]						[85]	[99]	[50]	[112]

Species		*Saccharomyces cerevisiae* / *Hanseniaspora uvarum*			
Matrix		**Synthetic Medium**			**White Grape Juice / Must**
		SGJ	SGJ	SGJ	Macabeo
Sugar Initial Concentration (g/L)		200 (Glc 110 Fru 110)	200 (Glc 100 Fru 100)	200 (Glc 100 Fru 100)	180
YAN / PAN (mg/L)			YAN 410	YAN 200	YAN 114.6
Temperature (°C)		18	25	20	20
Oxygenation		+	++	+	+
Inoculation delay between 2 strains (h)		0	0	0	0
Ratio Sc/NS		4:1	1:1	1:10	1:9
Sc population	**Max**	2		1	
	Dominance				
	Decrease	-		8	
NS population	**Max**		1	1	1
	Decrease	1	2	1	5
	Detectable End	No 3	No 4	Low 10	No 10
Fermentation completion		18			+
Ethanol			=	+	=
Glycerol				-	++
Organic acids	**TA**				
	VA				
	LA				
	AA				++
Impacting Factors		RAT	SPE / NS	SPE	SPE
Interaction Mechanisms		TOX / Not COMP	TOX	COMP / TOX	COMP
Reference		[52]	[65]	[95]	[48]

YAN = yeast assimilable nitrogen / **PAN** = primary amino nitrogen. **Sc** = *S. cerevisiae* / **NS** = Non-*Saccharomyces*. **TA** = total acidity / **VA** = volatile acidity / **LA** = lactic acid / **AA** = acetic acid. **SGJ** = Synthetic Grape Juice / **Glc** = Glucose / **Fru** = Fructose / **WYPD** = Yeast Peptone Dextrose medium modified for wine fermentation / **Supp** = with supplementation. **Oxygen**: **-** = anaerobia, +/- semi-anaerobia, low oxygenation, + = semi-anaerobia, ++ aerobia, +++ aerobia, with higher oxygenation. **Population columns**: **Max =** maximal population reached by day x / **Dominance**: + = dominance of *S. cerevisiae*, = similar populations, "x" = dominance obtained after x days / **Decrease** = decrease since day x / **Low** = low population since day x / **No** = population not detectable since day x / **Yes** = population still detectable at day x. **Fermentation completion**: x = reached at day x, +/- = reached/not reached during experimentation. **Ethanol, glycerol and organic acids** are compared to Sc pure culture: +++ very high increase ++ high increase, + increase, +/- slight decrease, = no change, - decrease, - - high decrease. **Impacting factors**: inoculation delay (**DEL**), inoculation ratio between *S. cerevisiae* and non-*Saccharomyces* yeast (**RAT**), yeast species (**SPE**), yeast strain *S. cerevisiae* (**SC**) or non-

Saccharomyces (**NS**), medium composition (**MED**), grape nature (**GRA**), temperature (**TEMP**), oxygenation (**OX**), type of reactor (lab, pilot, industrial) (**REAC**). **Interaction mechanisms**: involvement of quorum sensing mechanisms (**QS**), toxic compounds (including ethanol, antimicrobial peptides) (**TOX**), competition for nutrient (including oxygen) (**COMP**), cell-cell contact mechanisms (**CCC**) / **No** = mechanism involvement has been ruled out by the study.