

Supplementary Table 1. Mechanisms underlying the antagonistic activity of yeasts. Different types of biocontrol mechanisms are divided into different specific mechanisms that were studied in distinct yeast species. Key studies and findings for all the specific mechanisms in different species are given without the claim for completeness. This overview is limited to studies that directly link specific properties/enzymes/metabolites to antibacterial or antifungal activity.

Type of mechanism	Specific mechanism	Species	References
Competition for nutrients & space	Rapid nitrogen/amino acid depletion	<i>Metschnikowia reukaufii</i>	Dhami et al. 2016
	General competition for nutrients	<i>Cryptococcus laurentii</i>	Castoria et al. 1997
		<i>Rhodotorula glutinis</i>	Castoria et al. 1997
	Iron deprivation	<i>Aureobasidium pullulans</i>	Wang et al. 2009a; Wang et al. 2009b
		<i>Metschnikowia pulcherrima</i>	Gore-Lloyd et al. 2019; Saravanakumar et al. 2008; Sipiczki 2006
	Sulfur metabolism	<i>Saccharomycopsis schoenii</i>	Junker et al. 2019
	Biofilm formation	<i>Aureobasidium pullulans</i>	Klein and Kupper 2018; Wachowska et al. 2016
		<i>Kloeckera apiculata</i>	Pu et al. 2014
		<i>Metschnikowia pulcherrima</i>	Parafati et al. 2015
		<i>Pichia fermentans</i>	Fiori et al. 2012; Giobbe et al. 2007; Maserti et al. 2015; Sanna et al. 2013; Sanna et al. 2012
		<i>Pichia kudriavzevii</i>	Chi et al. 2015
		<i>Saccharomyces cerevisiae</i>	Ortu et al. 2005; Scherm et al. 2003
		<i>Wickerhamomyces anomalus</i>	Parafati et al. 2015
Secreted enzymes	Chitinases	<i>Aureobasidium pullulans</i>	Zajc et al. 2019
		<i>Candida oleophila</i>	Bar-Shimon et al. 2004
		<i>Cryptococcus albidus</i>	Chan and Tian 2005

	<i>Debaryomyces hansenii</i>	Zajc et al. 2019
	<i>Metschnikowia fruticola</i>	Zajc et al. 2019
	<i>Metschnikowia pulcherrima</i>	Saravanakumar et al. 2009
	<i>Meyerozyma guilliermondii</i>	Zajc et al. 2019
	<i>Pichia guilliermondii</i>	Zhang et al. 2011
	<i>Pichia methanolica</i>	Pretscher et al. 2018
	<i>Pichia membranifaciens</i>	Chan and Tian 2005
	<i>Saccharomyces cerevisiae</i>	Lopes et al. 2015
	<i>Saccharomycopsis schoenii</i>	Junker et al. 2019
	<i>Tilletiopsis sp.</i>	Urquhart and Punja 2002
	<i>Wickerhamomyces anomalus</i>	Pretscher et al. 2018
Glucanases	<i>Apiotrichum mycotoxinovorans</i>	Pretscher et al. 2018
	<i>Candida oleophila</i>	Bar-Shimon et al. 2004; Segal et al. 2002; Yehuda et al. 2003
	<i>Cryptococcus albidus</i>	Chan and Tian 2005
	<i>Cryptococcus laurentii</i>	Castoria et al. 1997
	<i>Metschnikowia pulcherrima</i>	Pretscher et al. 2018
	<i>Pichia guilliermondii</i>	Zhang et al. 2011
	<i>Pichia membranifaciens</i>	Chan and Tian 2005
	<i>Pichia methanolica</i>	Pretscher et al. 2018
	<i>Rhodotorula glutinis</i>	Castoria et al. 1997
	<i>Saccharomyces cerevisiae</i>	Lopes et al. 2015
	<i>Saccharomycopsis schoenii</i>	Junker et al. 2019
	<i>Tilletiopsis sp.</i>	Urquhart and Punja 2002

		<i>Wickerhamomyces anomalus (Pichia anomala)</i>	Friel et al. 2007; Grevesse et al. 2003; Parafati et al. 2017
Lipases	Environmental isolates of ascomycete and basidiomycete yeasts		Arroyo-Lopez et al. 2008; Buzzini and Martini 2002; Hernandez et al. 2007
Proteases		<i>Aureobasidium pullulans</i>	Banani et al. 2014; Zhang et al. 2012
		<i>Candida oleophila</i>	Bar-Shimon et al. 2004
		<i>Metschnikowia pulcherrima</i>	Pretscher et al. 2018
		<i>Pichia methanolica</i>	Pretscher et al. 2018
		<i>Saccharomycopsis schoenii</i>	Junker et al. 2019
		<i>Wickerhamomyces anomalus</i>	Pretscher et al. 2018
Toxin production	Killer toxin / Killer activity	<i>Candida guilliermondii</i>	Coelho et al. 2009
		<i>Candida nodaensis</i>	da Silva et al. 2008
		<i>Debaryomyces hansenii</i>	Banjara et al. 2016; Corbaci and Ucar 2018; Marquina et al. 2001; Santos et al. 2002
		<i>Debaryomyces robertsiae</i>	Klassen et al. 2004
		<i>Kluyveromyces siamensis</i>	Buzdar et al. 2011
		<i>Kluyveromyces wickerhamii</i>	Comitini and Ciani 2011
		<i>Mrakia frigida</i>	Hua et al. 2010
		<i>Pichia acaciae</i>	Klassen et al. 2004
		<i>Pichia anomala</i>	De Ingeniis et al. 2009; Wang et al. 2007
		<i>Pichia farinosa</i>	Suzuki and Nikkuni 1994
		<i>Pichia kudriavzevii</i>	Bajaj et al. 2013
		<i>Pichia membranifaciens</i>	Belda et al. 2017; Santos and Marquina 2004a; Santos and Marquina 2004b; Santos et al. 2009
		<i>Pichia ohmeri</i>	Coelho et al. 2009
		<i>Pseudozyma tsukubaensis</i>	Golubev et al. 2006

	<i>Saccharomyces cerevisiae</i>	Lopes et al. 2015; Rodriguez-Cousino et al. 2011
	<i>Saccharomyces paradoxus</i>	Vepstaite-Monstavice et al. 2018
	<i>Schwanniomyces occidentalis</i>	Chen et al. 2000
	<i>Torulaspora delbrueckii</i>	Ramirez et al. 2015; Villalba et al. 2016
	<i>Tetrapisispora phaffii</i> (<i>Kluyveromyces phaffii</i>)	Chessa et al. 2017; Comitini et al. 2004; Comitini et al. 2009
	<i>Wickerhamomyces anomalus</i>	Guo et al. 2013
	<i>Williopsis saturnus</i>	Buzzini et al. 2004; Guyard et al. 2002a; Guyard et al. 2002b; Wang et al. 2012
	<i>Williopsis mrakii</i> (<i>Hansenula mrakii</i>)	Kasahara et al. 1994a; Kasahara et al. 1994b; Lowes et al. 2000
	<i>Zygosaccharomyces bailii</i>	Weiler and Schmitt 2003
Flocculosin	<i>Pseudozyma flocculosa</i>	Mimee et al. 2009; Mimee et al. 2005; Teichmann et al. 2011
Aureobasidins	<i>Aureobasidium pullulans</i>	Takesako et al. 1991
2-propylacrylic acid, 2-methylenesuccinic acid	<i>Aureobasidium pullulans</i>	Zain et al. 2009
Liamocin	<i>Aureobasidium pullulans</i>	Price et al. 2017
Unidentified toxins	<i>Tilletiopsis sp.</i>	Urquhart and Punja 2002
Volatile organic compounds	2-phenylethanol and others	Di Francesco et al. 2014
	<i>Candida friedrichii</i>	Farbo et al. 2018
	<i>Candida intermedia</i>	Farbo et al. 2018
	<i>Cyberlindnera jadinii</i>	Farbo et al. 2018
	<i>Lachancea thermotolerans</i>	Farbo et al. 2018
	<i>Saccharomyces cerevisiae</i>	Fialho et al. 2010

		<i>Wickerhamomyces anomalus (Pichia anomala)</i>	Hua et al. 2014
		<i>Williopsis mrakii</i>	Bruce et al. 2003
2-phenylethyl acetate and others		<i>Hanseniaspora uvarum</i>	Masoud et al. 2005
		<i>Pichia kluyveri</i>	Masoud et al. 2005
2-phenylethyl acetate and others		<i>Wickerhamomyces anomalus (Pichia anomala)</i>	Masoud et al. 2005
2-ethyl-1-hexanol		<i>Sporidiobolus pararoseus</i>	Huang et al. 2012
1,3,5,7-cyclooctatetraene, 3-methyl-1-butanol and others		<i>Candida intermedia</i>	Huang et al. 2011
Unidentified volatiles		<i>Aureobasidium pullulans</i>	Parafati et al. 2015
		<i>Candida sake</i>	Arrarte et al. 2017
		<i>Metschnikowia pulcherrima</i>	Parafati et al. 2015
		<i>Saccharomyces cerevisiae</i>	Lopes et al. 2015; Oro et al. 2017; Parafati et al. 2015
		<i>Starmerella bacillaris</i>	Lemos et al. 2016
		<i>Wickerhamomyces anomalus</i>	Parafati et al. 2015
Fungivory / direct parasitization		<i>Saccharomycopsis schoenii</i>	Junker et al. 2018; Junker et al. 2019
		<i>Pichia guilliermondii</i>	Wisniewski et al. 1991
		<i>Pseudozyma aphidis</i>	Calderon et al. 2019; Gafni et al. 2015
Indirect mechanisms	Induction of resistance	<i>Candida oleophila</i>	Droby et al. 2002
		<i>Candida saitoana</i>	El Ghaouth et al. 2003; Hadwiger et al. 2015
		<i>Curibasidium pallidicorallinum</i>	Hadwiger et al. 2015
		<i>Kloeckera apiculata</i>	Liu et al. 2016
		<i>Metschnikowia fructicola</i>	HersHKovitz et al. 2012

<i>Metschnikowia pulcherrima</i>	Hadwiger et al. 2015
<i>Pseudozyma aphidis</i>	Barda et al. 2015; Buxdorf et al. 2013a; Buxdorf et al. 2013b; Calderon et al. 2019; Gafni et al. 2015
<i>Pseudozyma churashimaensis</i>	Lee et al. 2017
<i>Rhodospiridium paludigenum</i>	Lu et al. 2014; Lu et al. 2013; Sun et al. 2018
<i>Saccharomyces cerevisiae</i> (including cell walls)	De Miccolis Angelini et al. 2019; Shalaby and El-Nady 2008

REFERENCES

- Arrarte E, Garmendia G, Rossini C, Wisniewski M, Vero S (2017) Volatile organic compounds produced by Antarctic strains of *Candida sake* play a role in the control of postharvest pathogens of apples Biol Control 109:14-20 doi:10.1016/j.biocontrol.2017.03.002
- Arroyo-Lopez FN, Querol A, Bautista-Gallego J, Garrido-Fernandez A (2008) Role of yeasts in table olive production Int J Food Microbiol 128:189-196 doi:10.1016/j.ijfoodmicro.2008.08.018
- Bajaj BK, Raina S, Singh S (2013) Killer toxin from a novel killer yeast *Pichia kudriavzevii* RY55 with idiosyncratic antibacterial activity J Basic Microbiol 53:645-656 doi:10.1002/jobm.201200187
- Banani H, Spadaro D, Zhang D, Matic S, Garibaldi A, Gullino ML (2014) Biocontrol activity of an alkaline serine protease from *Aureobasidium pullulans* expressed in *Pichia pastoris* against four postharvest pathogens on apple Int J Food Microbiol 182-183:1-8 doi:10.1016/j.ijfoodmicro.2014.05.001
- Banjara N, Nickerson KW, Suhr MJ, Hallen-Adams HE (2016) Killer toxin from several food-derived *Debaryomyces hansenii* strains effective against pathogenic *Candida* yeasts Int J Food Microbiol 222:23-29 doi:10.1016/j.ijfoodmicro.2016.01.016
- Bar-Shimon M et al. (2004) Characterization of extracellular lytic enzymes produced by the yeast biocontrol agent *Candida oleophila* Curr Genet 45:140-148 doi:10.1007/s00294-003-0471-7
- Barda O, Shalev O, Alster S, Buxdorf K, Gafni A, Levy M (2015) *Pseudozyma aphidis* induces salicylic-acid-independent resistance to *Clavibacter michiganensis* in tomato plants Plant Dis 99:621-626 doi:10.1094/PLDIS-04-14-0377-RE
- Belda I, Ruiz J, Alonso A, Marquina D, Santos A (2017) The biology of *Pichia membranifaciens* killer toxins Toxins (Basel) 9 doi:10.3390/toxins9040112
- Bruce A, Stewart D, Verrall S, Wheatley RE (2003) Effect of volatiles from bacteria and yeast on the growth and pigmentation of sapstain fungi Int Biodeterior Biodegradation 51:101-108 doi:10.1016/S0964-8305(02)00088-4
- Buxdorf K, Rahat I, Gafni A, Levy M (2013a) The epiphytic fungus *Pseudozyma aphidis* induces jasmonic acid- and salicylic acid/nonexpressor of PR1-independent local and systemic resistance Plant Physiol 161:2014-2022 doi:10.1104/pp.112.212969
- Buxdorf K, Rahat I, Levy M (2013b) *Pseudozyma aphidis* induces ethylene-independent resistance in plants Plant Signal Behav 8:e26273 doi:10.4161/psb.26273
- Buzdar MA, Chi Z, Wang Q, Hua MX, Chi ZM (2011) Production, purification, and characterization of a novel killer toxin from *Kluyveromyces siamensis* against a pathogenic yeast in crab Appl Microbiol Biotechnol 91:1571-1579 doi:10.1007/s00253-011-3220-8
- Buzzini P, Corazzi L, Turchetti B, Buratta M, Martini A (2004) Characterization of the *in vitro* antimycotic activity of a novel killer protein from *Williopsis saturnus* DBVPG 4561 against emerging pathogenic yeasts FEMS Microbiol Lett 238:359-365 doi:10.1016/j.femsle.2004.07.060

- Buzzini P, Martini A (2002) Extracellular enzymatic activity profiles in yeast and yeast-like strains isolated from tropical environments J Appl Microbiol 93:1020-1025 doi:10.1046/j.1365-2672.2002.01783.x|
- Calderon CE, Rotem N, Harris R, Vela-Corcia D, Levy M (2019) *Pseudozyma aphidis* activates reactive oxygen species production, programmed cell death and morphological alterations in the necrotrophic fungus *Botrytis cinerea* Mol Plant Pathol 20:562-574 doi:10.1111/mpp.12775
- Castoria R, De Curtis F, Lima G, De Cicco V (1997) β -1,3-glucanase activity of two saprophytic yeasts and possible mode of action as biocontrol agents against postharvest diseases Postharvest Biol Technol 12:293-300 doi:10.1016/S0925-5214(97)00061-6
- Chan Z, Tian S (2005) Interaction of antagonistic yeasts against postharvest pathogens of apple fruit and possible mode of action Postharvest Biol Technol 36:215-223 doi:10.1016/j.postharvbio.2005.01.001
- Chen WB, Han YF, Jong SC, Chang SC (2000) Isolation, purification, and characterization of a killer protein from *Schwanniomyces occidentalis* Appl Environ Microbiol 66:5348-5352 doi:10.1128/aem.66.12.5348-5352.2000
- Chessa R et al. (2017) Biotechnological exploitation of *Tetrapisispora phaffii* killer toxin: heterologous production in *Komagataella phaffii* (*Pichia pastoris*) Appl Microbiol Biotechnol 101:2931-2942 doi:10.1007/s00253-016-8050-2
- Chi M et al. (2015) Increase in antioxidant enzyme activity, stress tolerance and biocontrol efficacy of *Pichia kudriavzevii* with the transition from a yeast-like to biofilm morphology Biol Cont 90:113-119 doi:10.1016/j.biocontrol.2015.06.006
- Coelho AR, Tachi M, Pagnocca FC, Nobrega GM, Hoffmann FL, Harada K, Hirooka EY (2009) Purification of *Candida guilliermondii* and *Pichia ohmeri* killer toxin as an active agent against *Penicillium expansum* Food Addit Contam Part A Chem Anal Control Expo Risk Assess 26:73-81 doi:10.1080/02652030802227227
- Comitini F, Ciani M (2011) *Kluyveromyces wickerhamii* killer toxin: purification and activity towards *Brettanomyces/Dekkera* yeasts in grape must FEMS Microbiol Lett 316:77-82 doi:10.1111/j.1574-6968.2010.02194.x
- Comitini F, Di Pietro N, Zacchi L, Mannazzu I, Ciani M (2004) *Kluyveromyces phaffii* killer toxin active against wine spoilage yeasts: purification and characterization Microbiology 150:2535-2541 doi:10.1099/mic.0.27145-0
- Comitini F, Mannazzu I, Ciani M (2009) *Tetrapisispora phaffii* killer toxin is a highly specific beta-glucanase that disrupts the integrity of the yeast cell wall Microb Cell Fact 8:55 doi:10.1186/1475-2859-8-55
- Corbaci C, Ucar FB (2018) Purification, characterization and in vivo biocontrol efficiency of killer toxins from *Debaryomyces hansenii* strains Int J Biol Macromol 119:1077-1082 doi:10.1016/j.ijbiomac.2018.07.121
- da Silva S, Calado S, Lucas C, Aguiar C (2008) Unusual properties of the halotolerant yeast *Candida nodaensis* killer toxin, CnKT Microbiol Res 163:243-251 doi:10.1016/j.micres.2007.04.002
- De Ingeniis J, Raffaelli N, Ciani M, Mannazzu I (2009) *Pichia anomala* DBVPG 3003 secretes a ubiquitin-like protein that has antimicrobial activity Appl Environ Microbiol 75:1129-1134 doi:10.1128/AEM.01837-08
- De Miccolis Angelini RM, Rotolo C, Gerin D, Abate D, Pollastro S, Faretra F (2019) Global transcriptome analysis and differentially expressed genes in grapevine after application of the yeast-derived defense inducer cerevisane Pest Manag Sci 75:2020-2033 doi:10.1002/ps.5317
- Dhami MK, Hartwig T, Fukami T (2016) Genetic basis of priority effects: insights from nectar yeast Proc Biol Sci 283 doi:10.1098/rspb.2016.1455
- Di Francesco A, Ugolini L, Lazzeri L, Mari M (2014) Production of volatile organic compounds by *Aureobasidium pullulans* as a potential mechanism of action against postharvest fruit pathogens Biol Control 81:8-14 doi:10.1016/j.biocontrol.2014.10.004
- Droby S, Vinokur V, Weiss B, Cohen L, Daus A, Goldschmidt EE, Porat R (2002) Induction of resistance to *Penicillium digitatum* in grapefruit by the yeast biocontrol agent *Candida oleophila* Phytopathology 92:393-399 doi:10.1094/PHYTO.2002.92.4.393
- El Ghaouth A, Wilson CL, Wisniewski M (2003) Control of postharvest decay of apple fruit with *Candida saitoana* and induction of defense responses Phytopathology 93:344-348 doi:10.1094/PHYTO.2003.93.3.344
- Farbo MG et al. (2018) Effect of yeast volatile organic compounds on ochratoxin A-producing *Aspergillus carbonarius* and *A. ochraceus* Int J Food Microbiol 284:1-10 doi:10.1016/j.ijfoodmicro.2018.06.023
- Fialho MB, Toffano L, Pedroso MP, Augusto F, Pascholati SF (2010) Volatile organic compounds produced by *Saccharomyces cerevisiae* inhibit the *in vitro* development of *Guignardia citricarpa*, the causal agent of citrus black spot World J Microb Biot 26:925-932 doi:10.1007/s11274-009-0255-4

- Fiori S et al. (2012) Identification of differentially expressed genes associated with changes in the morphology of *Pichia fermentans* on apple and peach fruit FEMS Yeast Res 12:785-795 doi:10.1111/j.1567-1364.2012.00829.x
- Friel D, Pessoa NM, Vandenbol M, Jijakli MH (2007) Separate and combined disruptions of two α -1,3-glucanase genes decrease the efficiency of *Pichia anomala* (strain K) biocontrol against *Botrytis cinerea* on apple Mol Plant Microbe Interact 20:371-379 doi:10.1094/MPMI-20-4-0371
- Gafni A, Calderon CE, Harris R, Buxdorf K, Dafa-Berger A, Zeilinger-Reichert E, Levy M (2015) Biological control of the cucurbit powdery mildew pathogen *Podosphaera xanthii* by means of the epiphytic fungus *Pseudozyma aphidis* and parasitism as a mode of action Front Plant Sci 6:132 doi:10.3389/fpls.2015.00132
- Giobbe S, Marceddu S, Scherm B, Zara G, Mazzarello VL, Budroni M, Migheli Q (2007) The strange case of a biofilm-forming strain of *Pichia fermentans*, which controls *Monilinia* brown rot on apple but is pathogenic on peach fruit FEMS Yeast Res 7:1389-1398 doi:10.1111/j.1567-1364.2007.00301.x
- Golubev WI, Pfeiffer I, Golubeva EW (2006) Mycocin production in *Pseudozyma tsukubaensis* Mycopathologia 162:313-316 doi:10.1007/s11046-006-0065-2
- Gore-Lloyd D et al. (2019) Snf2 controls pulcherriminic acid biosynthesis and antifungal activity of the biocontrol yeast *Metschnikowia pulcherrima* Mol Microbiol 112:317-332 doi:10.1111/mmi.14272
- Grevesse C, Lepoivre P, Jijakli MH (2003) Characterization of the exoglucanase-encoding gene *PaEXG2* and study of its role in the biocontrol activity of *Pichia anomala* strain K Phytopathology 93:1145-1152 doi:10.1094/PHYTO.2003.93.9.1145
- Guo FJ, Ma Y, Xu HM, Wang XH, Chi ZM (2013) A novel killer toxin produced by the marine-derived yeast *Wickerhamomyces anomalus* YF07b Antonie Van Leeuwenhoek 103:737-746 doi:10.1007/s10482-012-9855-3
- Guyard C, Dehecq E, Tissier JP, Polonelli L, Dei-Cas E, Cailliez JC, Menozzi FD (2002a) Involvement of [beta]-glucans in the wide-spectrum antimicrobial activity of *Williopsis saturnus* var. *mrakii* MUCL 41968 killer toxin Mol Med 8:686-694
- Guyard C et al. (2002b) Characterization of a *Williopsis saturnus* var. *mrakii* high molecular weight secreted killer toxin with broad-spectrum antimicrobial activity J Antimicrob Chemother 49:961-971 doi:10.1093/jac/dkf040
- Hadwiger LA, McDonel H, Glawe D (2015) Wild yeast strains as prospective candidates to induce resistance against potato late blight (*Phytophthora infestans*) Am J Potato Res 92:379-386 doi:10.1007/s12230-015-9443-y
- Hernandez A, Martin A, Aranda E, Perez-Nevado F, Cordoba MG (2007) Identification and characterization of yeast isolated from the elaboration of seasoned green table olives Food Microbiol 24:346-351 doi:10.1016/j.fm.2006.07.022
- Hershkovitz V et al. (2012) Global changes in gene expression of grapefruit peel tissue in response to the yeast biocontrol agent *Metschnikowia fructicola* Mol Plant Pathol 13:338-349 doi:10.1111/j.1364-3703.2011.00750.x
- Hua MX, Chi Z, Liu GL, Buzdar MA, Chi ZM (2010) Production of a novel and cold-active killer toxin by *Mrakia frigida* 2E00797 isolated from sea sediment in Antarctica Extremophiles 14:515-521 doi:10.1007/s00792-010-0331-6
- Hua SS, Beck JJ, Sarreal SB, Gee W (2014) The major volatile compound 2-phenylethanol from the biocontrol yeast, *Pichia anomala*, inhibits growth and expression of aflatoxin biosynthetic genes of *Aspergillus flavus* Mycotoxin Res 30:71-78 doi:10.1007/s12550-014-0189-z
- Huang R, Che HJ, Zhang J, Yang L, Jiang DH, Li GQ (2012) Evaluation of *Sporidiobolus pararoseus* strain YCXT3 as biocontrol agent of *Botrytis cinerea* on post-harvest strawberry fruits Biol Control 62:53-63 doi:10.1016/j.biocontrol.2012.02.010
- Huang R, Li GQ, Zhang J, Yang L, Che HJ, Jiang DH, Huang HC (2011) Control of postharvest *Botrytis* fruit rot of strawberry by volatile organic compounds of *Candida intermedia* Phytopathology 101:859-869 doi:10.1094/PHYTO-09-10-0255
- Junker K, Bravo Ruiz G, Lorenz A, Walker L, Gow NAR, Wendland J (2018) The mycoparasitic yeast *Saccharomycopsis schoenii* predates and kills multi-drug resistant *Candida auris* Sci Rep 8:14959 doi:10.1038/s41598-018-33199-z
- Junker K, Chailyan A, Hesselbart A, Forster J, Wendland J (2019) Multi-omics characterization of the necrotrophic mycoparasite *Saccharomycopsis schoenii* PLoS Pathog 15:e1007692 doi:10.1371/journal.ppat.1007692
- Kasahara S et al. (1994a) Involvement of cell wall beta-glucan in the action of HM-1 killer toxin FEBS Lett 348:27-32
- Kasahara S et al. (1994b) Cloning of the *Saccharomyces cerevisiae* gene whose overexpression overcomes the effects of HM-1 killer toxin, which inhibits beta-glucan synthesis J Bacteriol 176:1488-1499 doi:10.1128/jb.176.5.1488-1499.1994

- Klassen R, Teichert S, Meinhardt F (2004) Novel yeast killer toxins provoke S-phase arrest and DNA damage checkpoint activation Mol Microbiol 53:263-273 doi:10.1111/j.1365-2958.2004.04119.x
- Klein MN, Kupper KC (2018) Biofilm production by *Aureobasidium pullulans* improves biocontrol against sour rot in citrus Food Microbiol 69:1-10 doi:10.1016/j.fm.2017.07.008
- Lee G, Lee SH, Kim KM, Ryu CM (2017) Foliar application of the leaf-colonizing yeast *Pseudozyma churashimaensis* elicits systemic defense of pepper against bacterial and viral pathogens Sci Rep 7:39432 doi:10.1038/srep39432
- Lemos WJ, Jr. et al. (2016) Biocontrol ability and action mechanism of *Starmerella bacillaris* (synonym *Candida zemplinina*) isolated from wine musts against gray mold disease agent *Botrytis cinerea* on grape and their effects on alcoholic fermentation Front Microbiol 7:1249 doi:10.3389/fmicb.2016.01249
- Liu P, Chen K, Li G, Yang X, Long CA (2016) Comparative transcriptional profiling of orange fruit in response to the biocontrol yeast *Kloeckera apiculata* and its active compounds BMC Genomics 17:17 doi:10.1186/s12864-015-2333-3
- Lopes MR, Klein MN, Ferraz LP, da Silva AC, Kupper KC (2015) *Saccharomyces cerevisiae*: a novel and efficient biological control agent for *Colletotrichum acutatum* during pre-harvest Microbiol Res 175:93-99 doi:10.1016/j.micres.2015.04.003
- Lowes KF, Shearman CA, Payne J, MacKenzie D, Archer DB, Merry RJ, Gasson MJ (2000) Prevention of yeast spoilage in feed and food by the yeast mycocin HMK Appl Environ Microbiol 66:1066-1076
- Lu L, Xu S, Zeng L, Zheng X, Yu T (2014) *Rhodosporidium paludigenum* induced resistance in Ponkan mandarin against *Penicillium digitatum* requires ethylene-dependent signaling pathway Postharvest Biol Technol 97:93-101 doi:10.1016/j.postharvbio.2014.06.007
- Lu L et al. (2013) Preharvest application of antagonistic yeast *Rhodosporidium paludigenum* induced resistance against postharvest diseases in mandarin orange Biol Control 67:130-136 doi:10.1016/j.biocontrol.2013.07.016
- Marquina D, Barroso J, Santos A, Peinado JM (2001) Production and characteristics of *Debaryomyces hansenii* killer toxin Microbiol Res 156:387-391 doi:10.1078/0944-5013-00117
- Maserti B, Podda A, Giorgetti L, Del Carratore R, Chevret D, Migheli Q (2015) Proteome changes during yeast-like and pseudohyphal growth in the biofilm-forming yeast *Pichia fermentans* Amino Acids 47:1091-1106 doi:10.1007/s00726-015-1933-1
- Masoud W, Poll L, Jakobsen M (2005) Influence of volatile compounds produced by yeasts predominant during processing of *Coffea arabica* in East Africa on growth and ochratoxin A (OTA) production by *Aspergillus ochraceus* Yeast 22:1133-1142 doi:10.1002/yea.1304
- Mimee B, Labbe C, Belanger RR (2009) Catabolism of flocculosin, an antimicrobial metabolite produced by *Pseudozyma flocculosa* Glycobiology 19:995-1001 doi:10.1093/glycob/cwp078
- Mimee B, Labbe C, Pelletier R, Belanger RR (2005) Antifungal activity of flocculosin, a novel glycolipid isolated from *Pseudozyma flocculosa* Antimicrob Agents Chemother 49:1597-1599 doi:10.1128/AAC.49.4.1597-1599.2005
- Oro L, Feliziani E, Ciani M, Romanazzi G, Comitini F (2017) Volatile organic compounds from *Wickerhamomyces anomalus*, *Metschnikowia pulcherrima* and *Saccharomyces cerevisiae* inhibit growth of decay causing fungi and control postharvest diseases of strawberries Int J Food Microbiol 265:18-22 doi:10.1016/j.ijfoodmicro.2017.10.027
- Ortu G, Demontis MA, Budroni M, Goyard S, d'Enfert C, Migheli Q (2005) Study of biofilm formation in *Candida albicans* may help understanding the biocontrol capability of a *flor* strain of *Saccharomyces cerevisiae* against the phytopathogenic fungus *Penicillium expansum* J Plant Pathol 87:300
- Parafati L, Cirvilleri G, Restuccia C, Wisniewski M (2017) Potential role of exoglucanase genes (*WaEXG1* and *WaEXG2*) in the biocontrol activity of *Wickerhamomyces anomalus* Microb Ecol 73:876-884 doi:10.1007/s00248-016-0887-5
- Parafati L, Vitale A, Restuccia C, Cirvilleri G (2015) Biocontrol ability and action mechanism of food-isolated yeast strains against *Botrytis cinerea* causing post-harvest bunch rot of table grape Food Microbiol 47:85-92 doi:10.1016/j.fm.2014.11.013
- Pretscher J et al. (2018) Yeasts from different habitats and their potential as biocontrol agents Fermentation 4:31 doi:10.3390/fermentation4020031
- Price NP, Bischoff KM, Leathers TD, Cosse AA, Manitchotpisit P (2017) Polyols, not sugars, determine the structural diversity of anti-streptococcal liamocins produced by *Aureobasidium pullulans* strain NRRL 50380 J Antibiot (Tokyo) 70:136-141 doi:10.1038/ja.2016.92
- Pu L, Jingfan F, Kai C, Chao-an L, Yunjiang C (2014) Phenylethanol promotes adhesion and biofilm formation of the antagonistic yeast *Kloeckera apiculata* for the control of blue mold on citrus FEMS Yeast Res 14:536-546 doi:10.1111/1567-1364.12139

- Ramirez M, Velazquez R, Maqueda M, Lopez-Pineiro A, Ribas JC (2015) A new wine *Torulaspora delbrueckii* killer strain with broad antifungal activity and its toxin-encoding double-stranded RNA virus Front Microbiol 6:983 doi:10.3389/fmicb.2015.00983
- Rodriguez-Cousino N, Maqueda M, Ambrona J, Zamora E, Esteban R, Ramirez M (2011) A new wine *Saccharomyces cerevisiae* killer toxin (Klus), encoded by a double-stranded rna virus, with broad antifungal activity is evolutionarily related to a chromosomal host gene Appl Environ Microbiol 77:1822-1832 doi:10.1128/AEM.02501-10
- Sanna ML, Zara G, Zara S, Migheli Q, Budroni M, Mannazzu I (2013) A putative phospholipase C is involved in *Pichia fermentans* dimorphic transition Biochim Biophys Acta 1840:344-349 doi:10.1016/j.bbagen.2013.09.030
- Sanna ML, Zara S, Zara G, Migheli Q, Budroni M, Mannazzu I (2012) *Pichia fermentans* dimorphic changes depend on the nitrogen source Fungal Biol 116:769-777 doi:10.1016/j.funbio.2012.04.008
- Santos A, Marquina D (2004a) Ion channel activity by *Pichia membranifaciens* killer toxin Yeast 21:151-162 doi:10.1002/yea.1069
- Santos A, Marquina D (2004b) Killer toxin of *Pichia membranifaciens* and its possible use as a biocontrol agent against grey mould disease of grapevine Microbiology 150:2527-2534 doi:10.1099/mic.0.27071-0
- Santos A, Marquina D, Barroso J, Peinado JM (2002) (1-->6)-Beta-D-glucan as the cell wall binding site for *Debaryomyces hansenii* killer toxin Lett Appl Microbiol 34:95-99 doi:10.1046/j.1472-765x.2002.01053.x
- Santos A, San Mauro M, Bravo E, Marquina D (2009) PMKT2, a new killer toxin from *Pichia membranifaciens*, and its promising biotechnological properties for control of the spoilage yeast *Brettanomyces bruxellensis* Microbiology 155:624-634 doi:10.1099/mic.0.023663-0
- Saravanakumar D, Clavorella A, Spadaro D, Garibaldi A, Gullino ML (2008) *Metschnikowia pulcherrima* strain MACH1 outcompetes *Botrytis cinerea*, *Alternaria alternata* and *Penicillium expansum* in apples through iron depletion Postharvest Biol Tec 49:121-128 doi:10.1016/j.postharvbio.2007.11.006
- Saravanakumar D, Spadaro D, Garibaldi A, Gullino ML (2009) Detection of enzymatic activity and partial sequence of a chitinase gene in *Metschnikowia pulcherrima* strain MACH1 used as post-harvest biocontrol agent Eur J Plant Pathol 123:183-193 doi:10.1007/s10658-008-9355-5
- Scherm B, Ortu G, Muzzu A, Budroni M, Arras G, Migheli Q (2003) Biocontrol activity of antagonistic yeasts against *Penicillium expansum* on apple J Plant Pathol 85:205-213
- Segal E, Yehuda H, Droby S, Wisniewski M, Goldway M (2002) Cloning and analysis of CoEXG1, a secreted 1,3- β -glucanase of the yeast biocontrol agent *Candida oleophila* Yeast 19:1171-1182 doi:10.1002/yea.910
- Shalaby ME-S, El-Nady MF (2008) Application of *Saccharomyces cerevisiae* as a biocontrol agent against *Fusarium* infection of sugar beet plants Acta Biologica Szegediensis 52:271-275
- Sipiczki M (2006) *Metschnikowia* strains isolated from botrytized grapes antagonize fungal and bacterial growth by iron depletion Appl Environ Microb 72:6716-6724 doi:10.1128/Aem.01275-06
- Sun C, Fu D, Lu H, Zhang J, Zheng X, Yu T (2018) Autoclaved yeast enhances the resistance against *Penicillium expansum* in postharvest pear fruit and its possible mechanisms of action Biol Control 119:51-58 doi:10.1016/j.biocontrol.2018.01.010
- Suzuki C, Nikkuni S (1994) The primary and subunit structure of a novel type killer toxin produced by a halotolerant yeast, *Pichia farinosa* J Biol Chem 269:3041-3046
- Takesako K et al. (1991) Aureobasidins, new antifungal antibiotics. Taxonomy, fermentation, isolation, and properties J Antibiot (Tokyo) 44:919-924 doi:10.7164/antibiotics.44.919
- Teichmann B, Labbe C, Lefebvre F, Bolker M, Linne U, Belanger RR (2011) Identification of a biosynthesis gene cluster for flocculosin a cellobiose lipid produced by the biocontrol agent *Pseudozyma flocculosa* Mol Microbiol 79:1483-1495 doi:10.1111/j.1365-2958.2010.07533.x
- Urquhart EJ, Punja ZK (2002) Hydrolytic enzymes and antifungal compounds produced by *Tilletiopsis* species, phyllosphere yeasts that are antagonists of powdery mildew fungi Can J Microbiol 48:219-229 doi:10.1139/w02-008
- Vepstaite-Monstavice I et al. (2018) *Saccharomyces paradoxus* K66 killer system evidences expanded assortment of helper and satellite viruses Viruses 10 doi:10.3390/v10100564
- Villalba ML, Susana Saez J, Del Monaco S, Lopes CA, Sangorin MP (2016) TdKT, a new killer toxin produced by *Torulaspora delbrueckii* effective against wine spoilage yeasts Int J Food Microbiol 217:94-100 doi:10.1016/j.ijfoodmicro.2015.10.006

- Wachowska U, Głowacka K, Mikołajczyk W, Kucharska K (2016) Biofilm of *Aureobasidium pullulans* var. *pullulans* on winter wheat kernels and its effect on other microorganisms Microbiology 85:523-530 doi:10.1134/S0026261716050192
- Wang W, Chi Z, Liu G, Buzdar MA, Chi Z, Gu Q (2009a) Chemical and biological characterization of siderophore produced by the marine-derived *Aureobasidium pullulans* HN6.2 and its antibacterial activity Biometals 22:965-972 doi:10.1007/s10534-009-9248-x
- Wang WL, Chi ZM, Chi Z, Li J, Wang XH (2009b) Siderophore production by the marine-derived *Aureobasidium pullulans* and its antimicrobial activity Bioresour Technol 100:2639-2641 doi:10.1016/j.biortech.2008.12.010
- Wang X, Chi Z, Yue L, Li J (2007) Purification and characterization of killer toxin from a marine yeast *Pichia anomala* YF07b against the pathogenic yeast in crab Curr Microbiol 55:396-3401 doi:10.1007/s00284-007-9010-y
- Wang XX, Chi Z, Peng Y, Wang XH, Ru SG, Chi ZM (2012) Purification, characterization and gene cloning of the killer toxin produced by the marine-derived yeast *Williopsis saturnus* WC91-2 Microbiol Res 167:558-563 doi:10.1016/j.micres.2011.12.001
- Weiler F, Schmitt MJ (2003) Zygocin, a secreted antifungal toxin of the yeast *Zygosaccharomyces bailii*, and its effect on sensitive fungal cells FEMS Yeast Res 3:69-76 doi:10.1016/s1567-1356(02)00126-5
- Wisniewski M, Biles C, Droby S, McLaughlin R, Wilson C, Chalutz E (1991) Mode of action of the postharvest biocontrol yeast, *Pichia guilliermondii* .1. Characterization of attachment to *Botrytis cinerea* Physiol Mol Plant P 39:245-258 doi:10.1016/0885-5765(91)90033-E
- Yehuda H, Droby S, Bar-Shimon M, Wisniewski M, Goldway M (2003) The effect of under- and overexpressed CoEXG1-encoded exoglucanase secreted by *Candida oleophila* on the biocontrol of *Penicillium digitatum* Yeast 20:771-780 doi:10.1002/yea.1006
- Zain M, Awaad A, A. Razzak A, Maitland D, El-Sayed N, Sakhawy M (2009) Secondary metabolites of *Aureobasidium pullulans* isolated from egyptian soil and their biological activity Journal of Applied Sciences Research 5:1582-1591
- Zajc J, Gostincar C, Cernosa A, Gunde-Cimerman N (2019) Stress-tolerant yeasts: opportunistic pathogenicity versus biocontrol potential Genes (Basel) 10:42 doi:10.3390/genes10010042
- Zhang D, Spadaro D, Garibaldi A, Gullino ML (2011) Potential biocontrol activity of a strain of *Pichia guilliermondii* against grey mold of apples and its possible modes of action Biol Control 57:193-201 doi:10.1016/j.biocontrol.2011.02.011
- Zhang D, Spadaro D, Valente S, Garibaldi A, Gullino ML (2012) Cloning, characterization, expression and antifungal activity of an alkaline serine protease of *Aureobasidium pullulans* PL5 involved in the biological control of postharvest pathogens Int J Food Microbiol 153:453-464 doi:10.1016/j.ijfoodmicro.2011.12.016