

Inactivation of Microorganisms in Nuts and Nut Pastes: Table and References

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Inactivation of microorganisms in nuts and nut pastes – published treatments

Process type	Treatment	Nut product tested	References
Chemical	Acid solutions or sprays	Almonds, Pecans, Pine nuts, Sesame seeds (tahini, hummus)	Beuchat et al., 2013; Ha and Kang, 2015; Olaimat et al., 2017a and 2017b; Olaimat et al., 2022a; Pao et al., 2006; Salazar et al., 2018
	Carbon nanofiber (Fe ₃ C/NC) suspension	Chestnuts	Xu et al., 2020
	Chlorine (bleach, sodium hypochlorite)	Coconut, Hazelnuts, Pecans, Walnuts	Beuchat and Mann, 2011a; Beuchat et al., 2012, 2013; Blessington et al., 2013; Walter et al., 2009; Weller et al., 2013
	Chlorine dioxide gas	Almonds, Sesame seeds	Chai et al., 2022; Golden et al., 2019; Lim et al., 2021; Rane et al., 2020, 2021; Tan et al., 2023; Wang et al., 2019; Wihodo et al., 2005
	Mild heat + ClO ₂ gas	Almonds	Wang et al., 2019
	(Mild heat +/- or moisture) + ClO ₂ gas	Almonds	Rane et al., 2021
	Essential oil (cinnamon)	Almonds	Tsai et al., 2017
	Essential oil vapor (cinnamon, oregano)	Sesame seeds	Xu et al., 2022
	Ethanol spray(s)	Almonds	Salazar et al., 2018
	Hydrogen peroxide (spray, dip)	Almonds	Salazar et al., 2018; Xu and Chen, 2023
	H ₂ O ₂ dip + UV	Almonds (whole, with or without skin)	Xu and Chen, 2023
	Methyl bromide	Almonds, Walnuts	Schade and King, 1977
	Nitrogen dioxide	Almonds	Oh and Liu, 2020
	Ozone	Almonds (inshell, kernels), Pistachios (inshell, kernels, ground), walnuts	Akbas and Ozdemir, 2006; Khattri, 2023; Perry et al., 2019; Rane et al., 2020
	5% NaCl brine (70°C, 10 min) + ozone	Pistachios (inshell)	Perry et al., 2019
	UV-C + hydrogen peroxide + ozone	Pistachios (inshell, kernels)	Hasani et al., 2020
	Peracetic acid	Almonds, Coconut, Hazelnuts, Pecans, Walnuts	Beuchat et al., 2012, 2013; Frelka and Harris, 2015; Pearson et al., 2018; Salazar et al., 2018; Walter et al., 2009; Weller et al., 2013
	Ethanol + peracetic acid	Pistachios (inshell, kernels)	Hasani et al., 2020
	Propylene oxide	Almonds (inshell and kernels), Cashews, Macadamias, Pecans	ABC, 2008a, 2008b; Beuchat, 1973; Blanchard and Hanlin, 1973; Danyluk et al., 2005; Saunders et al., 2018
	Supercritical carbon dioxide (scCO ₂)	Almonds	Chen et al., 2022
Thyme oil + scCO ₂	Almonds	Chen et al., 2022	

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Process type	Treatment	Nut product tested	References
Thermal	Controlled atmosphere + heat	Almonds (ground)	Cheng et al., 2017; Cheng and Wang, 2018
	Hot air (includes dry roasting)	Almonds, Coconut (desiccated-shredded), Macadamia nuts, Peanuts, Pecans, Pistachios (inshell), Sesame seeds (and tahini), Soaked walnuts	ABC, 2007c; Beuchat and Mann, 2011b; Brar and Danyluk, 2019; Casulli et al., 2021; den Bakker et al., 2021; Dhowlagher et al., 2021; Lieberman et al., 2023; Moussavi et al., 2020; Poirier et al., 2014; Prestes et al., 2019a, 2019b; Sanders and Calhoun, 2014; Torlak et al., 2013; Yang et al., 2010; Xu and Chen, 2023; Zhang et al., 2017
	Hot air + packing method (e.g., vacuum)	Almonds	Song and Kang, 2021; Xu and Chen, 2022
	Water activity + hot air + packaging	Almonds	Xu and Chen, 2022
	Hot air + 70% ethanol spray(s)	Almonds, Pecans, Pistachios, Walnuts	Salazar et al., 2017
	Hot air + UV	Almonds	Xu and Chen, 2023
	Hot water	Almonds, Pecans, Pistachios	ABC, 2007b; Beuchat and Mann, 2011a; Cuervo et al., 2016; Harris et al., 2012; Kharel et al., 2018; McKay et al., 2022; Moussavi et al., 2020
	Chlorine + hot water	Pecans	Beuchat and Mann, 2011a
	Indirect heating (water or silicon oil bath)	Almond butter, Peanut butter, Sesame (tahini), Tree nut butters (commercial: almond, almond + cashew, hazelnut)	He et al., 2011; Keller et al., 2012; Li et al., 2014; Liao, 2023; Ma et al., 2009; Pelaez et al., 2020; Quinn et al., 2021; Shachar and Yaron, 2006; Szpinak et al., 2022; Wright et al., 2018
	Infrared heating (gas catalytic IR)	Almonds	Bingol et al., 2011; Brandl et al., 2008; Yang et al., 2010
	Distilled water + gas catalytic IR	Almonds	Bari et al., 2009
	Dry roasting + gas catalytic IR	Almonds	Bari et al., 2009; Yang et al., 2010
	Electrolyzed water + gas catalytic IR	Almonds	Bari et al., 2009
	Hot water + gas catalytic IR	Almonds	Bari et al., 2009
	Ozonated water + gas catalytic IR	Almonds	Bari et al., 2009
	Superheated steam + gas catalytic IR	Almonds	Bari et al., 2010
	Infrared heating (near IR)	Almonds, Pine nuts	Ha and Kang, 2015
	Distilled water + near IR	Almonds, Pine nuts	Ha and Kang, 2015
	Lactic acid + near IR	Almonds, Pine nuts	Ha and Kang, 2015
	Infrared heating (quartz emitters)	Pistachios	Venkitasamy et al., 2017
	Dry heating + IR	Almonds, Pistachios	Venkitasamy et al., 2017, 2018
	Microwave heating	Peanut butter, Sesame (tahini)	Osaili et al., 2021; Song and Kang, 2016
	915 MHz	Peanut butter	Song and Kang, 2016
	2450 MHz	Sesame (tahini)	Osaili et al., 2021

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Thermal cont'd	Moist air convection heating	Almonds, Pistachios	Casulli et al., 2018, 2021; S. Jeong et al., 2009, 2011, 2017	
	Presoak + moist air convection heating	Pistachios	Casulli et al., 2018, 2021	
	Oil (includes roasting or hot oil)	Almonds, Peanuts, Pecans, Pistachios, Walnuts	ABC, 2007d; Abd et al., 2012; Beuchat and Mann, 2011b; Brar and Danyluk, 2019; Cuervo et al., 2016; Du et al., 2010; Meyer and Vaughn, 1969; Moussavi et al., 2020; Prestes et al., 2019b; Sanders and Calhoun, 2014	
	Radio frequency (RF) heating	Almonds, Hazelnuts (inshell) Pistachios, Sesame seeds, Walnuts (inshell)	Chen et al., 2021; Gao et al., 2011; S.-G. Jeong et al., 2017, 2019; Li et al., 2017; Salazar et al., 2018; Xu et al., 2022; Zhang et al., 2019	
	70% ethanol spray(s) + RF heating	Almonds, Pecans, Pistachios, Walnuts	Salazar et al., 2018	
	Modified atmosphere pre-storage + RF	Almonds	Cheng and Wang, 2019	
	Controlled atmosphere	Almonds	Cheng et al., 2020	
	Essential oil vapor + RF heating	Sesame seeds	Xu et al., 2022	
	Steam, saturated ($\leq 100^\circ\text{C}$)	Almonds, Cashews, Hazelnuts (inshell), Macadamia nuts, Pecans (shelled, inshell), Pistachios	ABC, 2007a; Ban and Kang, 2016; Ban et al., 2018; Chang et al., 2010; Kharel et al., 2023; Lee et al., 2006; Letchworth, 2020; McKay et al., 2022; Saunders et al., 2023	
	Steam, superheated ($125\text{--}200^\circ\text{C}$)	Almonds, Pecans, Pistachios	Ban and Kang, 2016; Ban et al., 2018	
	Steam, vacuum-assisted ($62\text{--}82^\circ\text{C}$)	Macadamia nuts	Acuff et al., 2020	
	Non-thermal	Bacteriophage cocktails	Sesame (hummus)	Tayyarcen et al., 2022
		High-intensity 405-nm light	Almonds	Lacombe et al., 2016
		High pressure processing	Almonds, Peanut butter, Sesame seeds	D'Souza et al., 2012; D'Souza et al., 2014; Goodridge et al., 2006; Grasso et al., 2010; Willford et al., 2008; Wuytack et al., 2003
Irradiation (electron beam)		Almonds, Peanut butter, Pecans	Cuervo et al., 2016; Hvizdzak et al., 2010; Karagöz et al., 2014; Mohammad et al., 2019; Prakash et al., 2010	
Irradiation (gamma rays)		Peanut butter, Pistachios, Walnuts, Sesame seeds (and hummus)	Ban and Kang, 2014; D'Oca et al., 2021; Olaimat et al., 2022b; Osaili and Al-Nabulsi, 2016; Song et al., 2019; Wilson-Kakashita et al., 1995	
Irradiation (X-rays)		Almonds (kernels, meal, butter), Walnuts	Jeong et al., 2012; Steinbrunner et al., 2019	
Non-thermal plasma		Almonds, Almonds (sliced), Hazelnuts, Pine nuts, Pistachios, Sesame seeds, Walnuts	Deng et al., 2007; Han et al., 2020; Hartanto, 2022; Hertwig et al., 2017; Lee et al., 2021; Niemira, 2012; Pignata et al., 2014; Shirani et al., 2020	
Pulsed light, intense (200-1000 nm)		Sesame seeds	Hwang et al., 2017	
Pulsed light, UV (100-280 nm)		Almonds, Walnuts	Harguindeguy et al., 2021; Izmirliloglu et al., 2020	
Pulsed light + water pre-treatment		Almonds	Liu et al., 2021	
Ultraviolet light (C region; 254 nm)	Almonds, Peanuts, Walnuts (inshell)	Ruiz-Hernández et al., 2021; Yun et al., 2022; Xu and Chen, 2023		

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