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Review Article

A Review on Supercritical Fluid Extraction (SFE) of Lycopene from Tomato and Tomato Products

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Abstract

Lycopene, an acyclic, open chain, unsaturated carotenoid having 13 double bonds, of which 11 are conjugated, arranged in a linear array, is considered to be a pigment of potential commercial importance in the emerging market for nutraceutical products because of its function as a health-promoting ingredient. Lycopene has received a great deal of attention as an effective antioxidant that can play an important role in reducing the risk of several chronic diseases. In this study, we reviewed extraction parameters of lycopene from tomato and tomato products by supercritical fluids and pre-extraction procedures. For extraction, temperature range as 50-110°C, extraction time range as 0.5-8.0 hours, extraction pressure range as 300-400 bar and using co-solvent, especially ethanol, are common parameters.

Keywords: Tomato, Lycopene, Extraction, SFE

1. Introduction

For many decades, scientific studies and research have focused on functional foods and extracting the components from them that are responsible for their nutraceutical activity (Choksi and Joshi 2007). An example of these components is lycopene. Lycopene, a carotenoid largely present in tomato and tomato-derived products, is the main component responsible for the typical red colour of tomatoes (Fernandez-Ruiz et al. 2010, Ciurlia et al. 2009, Barba et al. 2006).

Lycopene is an acyclic, open chain, unsaturated carotenoid having 13 double bonds, of which 11 are conjugated, arranged in a linear array, and has a molecular formula of $C_{40}H_{56}$ (Fernandez-Ruiz et al. 2010, Egydio et al. 2010) with molecular weight of 537 (Choudhary et al. 2009).

Lycopene and other carotenoids are found mostly in the outer pericarp with tomato skin containing 12 mg lycopene/100 g skin (wet basis) while whole mature tomato contains only 3.4 mg lycopene/ 100 g (wet basis) (Saldana et al. 2010). The industrial processing of tomato products produces lots of wastes, even though it is a potential source for carotenoid as lycopene, carotene). Ripe tomatoes are most abundant source of lycopene with over 90% concentrated in the skin, which constitutes the greater part of the waste (Kassama et al. 2008).

Lycopene is one of the best biological suppressants of free radicals, especially those derived from oxygen (Monteiro et al. 2009). It has the highest singlet oxygen-quenching rate of all carotenoids in biological systems (Choudhari and Singhal 2008). It has received a great deal of attention as an effective antioxidant that can play an important role in reducing the risk of several chronic diseases (Rao 2006, Agarwal and Rao 2000, Arab and Steck 2000, Giovannucci et al. 2002, Rao and Rao 2004, Stahl and Sies 1996). Recent epidemiological studies revealed that the intake of tomatoes and blood lycopene level are inversely associated with the risk of some diseases (Davis et al. 2003), especially developing cancers of several anatomical sites including the prostate gland, stomach, and lung (Periago et al. 2007, Choudhari and Anathanarayan, 2007). Also, there is growing evidence that lycopene reduces the risk of prostate cancer and the US Food and Drug

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Administration has allowed a qualified health claim for lycopene (Saldana et al. 2010, Cortes et al. 2009).

The main problem in obtaining lycopene is its solubility and stability; it is insoluble in water but soluble in highly toxic organic solvents, such as benzene, chloroform, metylene chloride and decomposes easily during the time. In order to overcome these difficulties and obtain lycopene without traces of organic solvents scientists have considered the use of supercritical fluid extraction (SFE) technique (Vasapollo et al. 2004, Choudhari and Singhal 2008). The use of more friendly solvents can improve lycopene extraction process for human consumption. One candidate is supercritical CO_2 (SC-CO_2), that is readily available, low cost, nonflammable and a safe solvent (Egydio et al. 2010). Supercritical fluid extraction is an advanced separation technique based which using the solvating power of fluids above their super critical point. One of the most frequently used supercritical fluids is carbon dioxide. The large molecular weight is known to inhibit solubility in supercritical CO_2 (Shi et al. 2009a).

There are several researchers dealing with supercritical fluid extraction of lycopene from tomato juice, seeds, pulp, skin and whole tomato. Extraction of lycopene from tomatoes by supercritical CO_2 fluid shows promise for less isomerization and decomposition (Shi et al. 2009b). CO_2 is neither toxic nor flammable and exhibits high selectivity as a result of low viscosity, high diffusivity and liquid-like density (Yi et al. 2009, Vagi et al. 2007). It also has a critical temperature (Tc= 304.1 °K) that makes it suitable for the extraction of many natural products under mild conditions. However CO_2 lacks polarity and the ability to form specific solvent-solute interaction. The addition of a small amount of polar solvent for a modifier role, such as water, ethanol, methylene chloride, and hexane, can greatly enhance its solvent power (Shi et al. 2009b).

In this study, we aimed to determine the optimum process conditions to obtain lycopene from tomato

Table 1. SFE applications of tomato, tomato products and, tomato by-products with SC-CO_2*.

Reference	Sample Type	SFE Type	Extraction Conditions					Efficiency (%) or Yield (µg/g raw tomato)
			Time/Temp.	**Flow Rate (Kg CO_2/h)**	**Pressure (bar)**	**Particle Size**	**Co-Solvent or Modifier**	
Egydio et al. 2010	Tomato juice	n.d.	3-6 h/80°C	0.051-0,102	350	-	-	76.9%
Lenucci et al. 2010	Tomato matrix and pure	Pilot scale SFE	3 h/65-70°C	18-20	450	0.5 mm	-	>80%
Cadoni et al. 2000	Tomato pulp and dry skin	Supelco SFE-400	0.5h/80°C	500cm^3/min	275.79	n.d.	Chloroform (1mL/2,5g sample)	64.41%
Ciurlia et al. 2007	Tomato pulp and skins	Pilot scale SFE	8h/60°C	10	400	1 mm	Tetrahydrof uran	72.5%
Huang et al. 2008	Tomato pomace	n.d.	1.8h/57°C	0.7 L/min	400	-	Ethanol (%16)	93%
Blanch et al. 2007	Tomato skin	Iberfluid (Madrid, Spain)	3h/50°C	n.d.	320	-	-	67.5%
Kassama et al. 2008	Tomato skin	Spe-ed SFE NP, Model 7013,	0.5h/62°C	3.5 L/min	450	0.5-1 mm	Ethanol (%14)	33%
Ollanketo et al. 2001	Tomato Skin	ISCO SFX 3560	0.83h/110°C	1.5 mL/min	405	Powdere d samples	Acetone (500µL/0,3 g sample)	100%
Shi et al. 2009a	Tomato Skin	Spe-ed SFE NP, Model 7013	n.d./75°C	3.5 L/min	350	1 mm	Ethanol (%10) and olive oil (%10)	73.3%

*: Optimum parameters of related research
n.d. : not defined

and tomato products by SFE technique with reviewing the studies of various researches.

2. SFE of Lycopene from Tomato and Tomato Products

2.1 Pre-extraction

It was observed during review studies that researches should be careful in specifying methods and process parameters during sample preparation before extraction process by considering the factors, which may affect occurrence of various chemical changes in its structure, in addition to the factors, which affect lycopene recovery.

Raising dry material content of the samples before the extraction process is important. General application in the use of samples like tomato pulp and tomato juice, intended for this purpose, employed centrifuging and then, decantation of supernatant (Lenucci et al. 2010, Huang et al. 2008) while tomato skin and industrial tomato waste were dried generally. Most popular method for this purpose was freeze-dryer (Blanch et al. 2007, Shi et al. 2009a, Saldana et al. 2010, Gomez-Prieto et al. 2003, Lenucci et al. 2010) however, other methods like drying with sunlight or at room temperature (Vasapollo et al. 2004, Ollanketo et al. 2001, Ciurlia et al. 2009, Baysal et al. 2000), drying under vacuum (Sabio et al. 2003), drying in oven (Nobre et al. 2009), and drying with warm air (air-drier) (Cadoni et al. 2000) were used. Targeted humidity ratio with drying process ranged between 0.8% and 10.6% while this value was approximately 5.8%. In some studies, samples were dipped into sodium metabisulfite in sun drying method for preservation (Baysal et al. 2000); however, this was not a frequently encountered application.

Particle size was generally made smaller after drying through various methods. Particle size was generally reduced below 2 mm while most frequently used particle size with this system was 1 mm and below (Ciurlia et al. 2009, Shi et al., 2009a, Kassama et al. 2008, Yi et al. 2009, Saldana et al. 2010, Vasapollo et al. 2004, Nobre et al. 2009, Sabio et al. 2003, Vagi et al. 2007). The smallest size was found as 0.3 mm (Vagi et al. 2007) while the biggest size was found as above 3 mm (>3 mm) (Baysal et al. 2000).

Positive effect of grinding samples before the extraction on the extraction yield was determined (Baysal et al. 2000, Nobre et al. 2009), and various parameters are recommended like reducing particle size to 0.5 mm (Lenucci et al. 2010), 1 mm (Vasapollo et al. 2004), and 0.3 mm (Vagi et al. 2007). General application for reducing this size may be set out as below 2 mm considering type of samples and pre-grinding operations. It was reported in some studies that sieving operation was carried out after size reduction operation (Saldana et al. 2010, Sabio et al. 2003); however, in general, extraction process took place directly or the samples were stored until this process. Nitrogen may be used in packaging and storage of the samples to be stored (Nobre et al. 2009, Blanch et al. 2007, Gomez-Prieto et al. 2003). The factors, which should be considered in packaging and storage of the samples, include presence of heat, light and O_2 while storage conditions at the level of <(-18°C) are generally preferred.

2.2 SFE Applications

Effects of process parameters, especially extraction temperature, extraction pressure, and the use and amount of co-solvent or modifier, on lycopene recovery rate and amount as well as nature and functional features of lycopene in the studies on lycopene recovery from tomato, tomato products and tomato industry's by-products through SFE method by using SC-CO_2 were reviewed. Data about optimum extraction conditions described in various studies are seen in Table 1 which was prepared as a result of reviewing described above. In assessing lycopene amount, the degree to which lycopene could be extracted from samples was considered mostly while assessments were made via the obtained lycopene amount. The criteria taken under consideration in assessing nature and functional features of lycopene are trans-cis isomerization, antioxidant activity and stability in frequency order.

2.2.1 Extraction Temperature

Optimum extraction temperature varies within a wide range like 50-110°C in the studies included in this review; however, most frequently reported value is 80°C for optimum parameter (Egydio et al. 2010, Cadoni et al. 2000, Sabio et al. 2003, Vagi et al. 2007). Any correlation with this value and characteristic of type of sample could not be found. Number of studies specifying temperature values above 80°C as an optimum process parameter is restricted (Topal et al. 2006, Yi et al. 2009, Ollanketo et al. 2001, Rozzi et al. 2002). Effect of the relation between high temperature application and antioxidant activity as well as stability on this issue is clear and understandable.

It was highlighted at the end of many studies that an increase in extraction temperature increased lycopene yield (Yi et al. 2009, Egydio et al. 2010, Cadoni et al. 2000, Huang et al. 2008, Kassama et al. 2008, Rozzi et al. 2002, Baysal et al. 2000). In some of these studies, effect of this effect along with pressure was highlighted. Different opinions take place about optimum extraction temperature. These opinions are based on the targeted results in the conducted study, and this value is generally reported as above 80°C in studies considering only lycopene amount (Ollanketo et al. 2001) while it generally ranges between 57°C and 80°C in the studies considering thermal degradation of lycopene. Type of the material to be extracted and pre-treatments as well as extraction pressure should be taken into account in examining and specifying the optimum value. However, the factors like the increase in thermal degradation risk as a result of an increase in extraction temperature (Baysal et al. 2000), and an increase in solubility of lycopene depending on needle-like structure and dispersion in tomato tissues as a result of increased temperature (Cadoni et al. 2000) are the factors, which should be noticed in any case.

2.2.2 Extraction Pressure and Time

Increases in extraction pressure increase yield in lycopene recovery (Nobre et al. 2009, Yi et al. 2009; Lenucci et al. 2010, Huang et al. 2008, Rozzi et al. 2002, Baysal et al. 2000) while applications employing pressure values ranging between 200 and 450 bar produce optimum results depending on other process parameters, especially extraction temperature, and/or type and features of product. Optimum pressure parameter in lycopene recovery through SFE method are generally reported between 300 and 400 bar; however, especially 400 bar was set out as the optimum process parameter with different extraction temperatures ranging between 40°C and 100°C (Ciurlia et al. 2009, Topal et al. 2006, Huang et al. 2008, Yi et al. 2009, Saldana et al. 2010). Optimum

Table 1. SFE applications of tomato, tomato products and, tomato by-products with SC-CO_2* (continued).

Reference	Sample Type	SFE Type	Extraction Conditions					Efficiency (%) or Yield (µg/g raw tomato)
			Time/Temp.	Flow Rate (Kg CO_2/h)	Pressure (bar)	Particle Size	Co-Solvent or Modifier	
Yi et al. 2009	Tomato Skin	Spe-ed SFE NP, Model 7100,	1.5h/100°C	1.5 mL/min	400	1 mm	-	31.25 µg/g
Gomez-Prieto et al. 2003	Tomato skins and pulp	Hewlett Packard 7680A	0.5h/40°C	4 mL/min	77-281	-	-	%69
Saldana et al. 2010	Tomato without seed	Newport Scientific Lab scale SFE	6h/40°C	0.5 L/min	400	0.5-1 mm	%5 Canola oil	~0.06mg/g
Vasapollo et al. 2004	Sun dried tomato	n.d.	66°C	20	450	1 mm	%10 Hazelnut oil	60%
Baysal et al. 2000	Tomato paste waste	Sitec Pilot Scale SFE	2 h/55°C	4	300	<3 mm	%5 Ethanol	53.93%
Nobre et al. 2009	Tomato industrial wastes	n.d.	5 h/60°C	0.59 g/min	300	0.36 mm	-	93%
Rozzi et al. 2002	Tomato industrial wastes	ISCO SFX 210	3.33h/86°C	2.5 mL/min	344.7	-	-	61%
Sabio et al. 2003	Tomato industrial wastes	Lab scale SFE	0.164h/80°C	0.792	300	345µm		88%
Topal et al. 2006	Waste tomato skin	n.d.	6.5h/100°C	2.5mL/min	400	n.d.	-	1.18 mg/g
Vagi et al. 2007	Dried tomato pomace (with skin and seed)	Lab scale SFE	n.d./80°C	2.0mL/min	460	0.3-0.6 mm	-	90.1%
*: Optimum parameters of related research n.d. : not defined								

extraction time ranges between 0.5 and 8.0 hours while it was found that this parameter is related to type of equipment and flow rate of CO_2.

2.2.3 Co-solvent or Modifier Application

Co-solvent or modifier application was carried out in approximately 50% of the studies under the present review. From the point of view of effectiveness of extraction, ethanol is the mostly used solvent among optimum process parameters with the usage rate ranging between 5.0% and 16.0% (Baysal et al. 2000, Saldana et al. 2010, Kassama et al. 2008, Shi et al. 2009a) while organic solvents like chloroform (Cadoni et al. 2000), tetrahydrofuran (Ciurlia et al. 2009), and acetone (Ollanketo et al. 2001) as well as vegetable oils like olive oil (Shi et al. 2009a), canola oil (Saldana et al. 2010) and hazelnut oil (Vassapollo et al. 2004) were employed for this purpose. However, general opinion is that an increase in the ratio of modifier or co-solvent increases yield (Shi et al. 2009a), and various optimum ratios and types, for this purpose, were reported like 5.0% ethanol (Baysal et al. 2000), 10.0% vegetable oil (Vasapollo et al. 2004), 5.0% olive oil + 5.0% ethanol (Shi et al. 2009a) and 14.0% ethanol (Kassama et al. 2008). It is believed that the use of vegetable oil (for example hazelnut oil) contributes to solubility of lycopene in solvent (Ciurlia et al. 2009). Furthermore, it was reported that there is a synergic effect between concentration of modifier and extraction temperature while it does exist between pressure and modifier concentration (Kassama et al. 2008); however, there are researchers reporting that the use of a modifier like ethanol, water, and olive oil increases lycopene yield independently from variations in temperature and pressure (Shi et al. 2009a).

2.2.4 Isomerization

Nobre et al. (2009) reported that extraction temperatures higher than 60°C may cause lycopene isomerization while this value was determined by Yi et al. (2009) as 70°C and by Vagi et al. (2007) as 80°C. Pilot or laboratorial size SFE equipments were used in the studies in general.

3. Conclusions

Determining optimum parameters for SFE applications and in addition, learning effects of these parameters on the process are important for the studies to be conducted for specifying methods and parameters for industrial size processes and for examining lycopene level of tomato and tomato products/by-products and for bio-efficacy of lycopene to be obtained from these parameters. These parameters should be reviewed as pre- and post-extraction.

Operations like drying, grinding, and sieving to be completed before the extraction can raise lycopene content significantly. Furthermore, drying samples or tomato materials in preparation stage for the extraction caused a decrease in trans-lycopene content of the obtained extract. Also extracting samples with low moisture content allows achieving higher yields in trans- lycopene recovery from industrial tomato waste compared with those with higher moisture content. There are many studies reporting that the use of a co-solvent or modifier, in addition to SC-CO_2 solvent, in SFE application increases extractable lycopene content and yield of the process (Shi et al. 2009a, Ciurlia et al. 2009, Kassama et al. 2008, Baysal et al. 2000, Vasapollo et al. 2004) while there are other studies reporting that if optimum process parameters are employed, highly pure lycopene may be obtained without using a modifier or co-solvent (Topal et al. 2006). Essential critical parameters were reported as temperature and pressure in lycopene recovery through SFE application by using SC-CO_2; however, flow rate of SC-CO_2 and extraction time were emphasized in some studies. Effect of the SC-CO_2 flow rate on efficiency is not clear. Although some researchers reported that flow rate of SC-CO_2 has not a significant effect on efficiency increase, there are other researchers reporting that flow rate increases efficiency along with other extraction factors.

Extraction time in SFE applications is shorter compared with that of solid-liquid extraction applications. Also, the interaction between extraction time and pressure during SFE has an effect on antioxidant activity. Data were obtained indicating that flow rate of SC-CO_2, extraction pressure and extraction temperature below 70°C have no effect on the recovered lycopene's antioxidant activity degree. The lycopene having the largest capacity with respect to antioxidant activity, removing free radicals, and quenching singlet oxygen, was produced through applying 40°C as extraction temperature. Isomerization is another significant quality parameter in addition to antioxidant activity relating to characteristic of lycopene. In any case, extraction under low pressure and temperature can inhibit trans-cis isomerization and also, the products should be protected against heat and O_2. Furthermore, process preferences aiming an increase in lycopene yield should not cause an increase in trans-cis isomerization.Also solubility of lycopene in SC-CO_2 has a significant role in efficiency of extraction. Solubility rises depending on both of pressure and temperature. Optimum temperature seems as 60- 70 °C while significant thermal degradation may be observed at 80°C. The solubility of lycopene in SC-CO_2 is at higher levels at low temperatures.

In brief, lycopene extraction from tomato, its products and by-products through SFE method by using SC-CO_2 with efficiency degree of 100% should not be targeted due to degradation of the product. The factors affecting lycopene yield are matrix type, particle size, lycopene content, flow rate of SC-CO_2, type and ratio of co-solvent/modifier, and pressure and temperature of the extraction

4. References

Agarwal, L., Rao, S. 2000. Carotenoids and chronic diseases. *Drug Metabol. Drug Interact.,* 17(1-4): 189-210.

Arab, L., Steck, S. 2000. Lycopene and cardiovascular disease. *Am. J. Clin. Nutr.,* 71: 1691S-1695S.

Barba, AIO., Hurtado, MC., Mata, MCS., Ruiz, VF., De Tesada, MLS. 2006. Application of a UV–vis detection-HPLC method for a rapid determination of lycopene and β-carotene in vegetables . *Food Chem.,* 95: 328-336.

Baysal, T., Ersus, S., Starmans, DAJ. 2000. Supercritical CO_2 Extraction of β-Carotene and Lycopene from Tomato Paste Waste. *J. Agric. Food Chem.,* 48: 5507-5511.

Blanch, GP., Del Castillo, ML., Del Mar Caja, M., Perez-Mendez, M., Sanchez-Cortes, S. 2007. Stabilization of all-trans-lycopene from tomato by encapsulation using cyclodextrins. *Food Chem.,* 105: 1335-1341.

Cadoni, E., De Giorgi, MR., Medda, E., Poma, G. 2000. Supercritical CO_2 extraction of lycopene and β-carotene from ripe tomatoes. *Dye. Pigment.,* 44: 27-32.

Choksi, PM., Joshi, CVY. 2007. A review on Lycopene-Extraction, Purification, Stability and Applications. *Int. J. Food Prop.,* 10 (2): 289-298.

Choudhari, SM., Ananthanarayan, L. 2007. Enzyme aided extraction of lycopene from tomato tissues. *Food Chem.,* 102(1): 77-81.

Choudhari, SM., Singhal, RS. 2008. Supercritical carbon dioxide extraction of lycopene from mated cultures of Blakeslea trispora NRRL 2895 and 2896. *J. Food Eng.,* 89 (3): 349-354.

Choudhary, R., Bowser, TJ., Weekler, P., Maness, NO., McGlynn, W. 2009. Rapid estimation of lycopene concentration in watermelon and tomato puree by fiber optic visible reflectance spectroscopy. *Postharvest Biol. Tec.,* 52 (1): 103-109.

Ciurlia, L., Bleve, M., Rescio, L. 2009. Supercritical carbon dioxide co-extraction of tomatoes (*Lycopersicum esculentum* L.) and hazelnuts (*Corylus avellana* L.): A new procedure in obtaining a source of natural lycopene. *J. Supercrit. Fluid.,* 49 (3): 338-344.

Clinton, S., Emenhaser, C., Schwartz, S. 1996. Cis-trans lycopene isomers carotenoids and retinol in human prostate. *Cancer Epidem. Biomar.,* 5: 823-833.

Cortes, JM., Vazquez, A., Santa-Maria, G., Blanch, GP., Villen, J. 2009. Pesticide residue analysis by RPLC–GC in lycopene and other carotenoids obtained from tomatoes by supercritical fluid extraction . *Food Chem.,* 113 (1): 280-284.

Davis, AR., Fish, WW., Perkins-Veazie, P. 2003. A rapid spectrophotometric method for analyzing lycopene content in tomato and tomato products. *Postharvest Biol. Tec.,* 28 (3): 425-430.

Egydio, JA., Moraes, AM., Rosa, PTV. 2010. Supercritical fluid extraction of lycopene from tomato juice and characterization of its antioxidation activity. *J. Supercit. Fluid.,* 54 (2): 159-164.

Fernandez-Ruiz, V., Torrecilla, JS., Camara, M., Mata, MCS., Shoemaker, C. 2010. Radial basis network analysis of color parameters to estimate lycopene content on tomato fruits. *Talanta,* 83 (1): 9-13.

Giovannucci, ERE., Liu, Y., Stampfer, MJ., Willet, WC. 2002. A prospective study of tomato products, lycopene, and prostate cancer risk. *J. Natl. Cancer I.,* 94 (5): 391-398.

Gomez-Prieto, MS., Mar Caja, M., Herrazi, M., Santa-Maria, G. 2003. Supercritical Fluid Extraction of All-Trans-Lycopene from Tomato. *J. Agric. Food Chem.,* 51: 3-7.

Hackett, MM., Lee, JH., Francis, D., Schwartz, SJ. 2004. Thermal Stability and Isomerization of

Lycopene in Tomato Oleoresins from Different Varieties. *J. Food Sci.,* 69 (7): 536-541.

Huang, W., Li, Z., Niu, H., Li, N., Zhang, J. 2008. Optimization of operating parameters for supercritical carbon dioxide extraction of lycopene by response surface methodology. *J. Food Eng.,* 89 (3): 298-302.

Kassama, LS., Shi, J., Mittal, GS. 2008. Optimization of supercritical fluid extraction of lycopene from tomato skin with cental composite rotatable design model. *Sep. Purif. Technol.,* 60 (3): 278-284.

Lenucci, MS., Caccioppola, A., Durante, M., Serrone, L., Leonardo, R., Piro, G., Dollessandro, G. 2010. Optimisation of biological and physical parameters for lycopene supercritical CO_2 extraction from ordinary and high-pigment tomato cultivars. *J. Sci. Food Agri.*, 90 (10): 1709-1718.

Monteiro, CS., Miguel, OG., Eugenia, BM., Da Silva Penteado, PTP., Haracemiv, SMC. 2009. Extraction of lycopene from tomato sauce with mushrooms (*Agaricus brasiliensis*), determined by high-performance liquid chromatography. *Int. J. Food Sci. Nutr.,* 60 (S1): 72-78.

Nobre, BP., Palavra, AF., Pessoa, FLP., Mendes, RL. 2009. Supercritical CO_2 extraction of trans-lycopene from Portuguese tomato industrial waste. *Food Chem.,* 116 (3): 680-685.

Ollanketo, M., Hartonen, K., Riekkola, ML., Holm, Y., Hiltunen, R. 2001. Supercritical carbon dioxide extraction of lycopene in tomato skins. *Eur. Food Res.Technol.,* 212 (5): 561-565.

Periago, MJ., Rincon, F., Jacob, K., Garcia-Alonso, J., Ros, G. 2007. Detection of key factors in the extraction and quantification of lycopene from tomato and tomato products. *J. Agri. Food Chem.,* 55 (22): 882-8829.

Rao, A., Rao, L. 2004. Lycopene and human health. *Curr. Top. Nutraceut. R.,* 2: 127-136.

Rao, AV. 2006. Diet and Chronic Diseases: Role of Phytonutrients. In: Tomatoes, Lycopene and Human Health; Preventing Chronic Diseases. Rao, A.V. ed. pp. 15-17. *Caledonian Sci. Pres.,* Scotland.

Rozzi, NL., Singh, RK., Vierling, RA., Watkins, BA. 2002. Supercritical Fluid Extraction of Lycopene from Tomato Processing Byproducts. *J. Agri. Food Chem.,* 50 (9): 2638-2643.

Sabio, E., Lozano, M., de Espinosa, VM., Mendes, RL., Pereira, AP., Palavra, AF., Coelho, JA. 2003. Lycopene and β-Carotene Extraction from Tomato Processing Waste Using Supercritical CO_2. *Ind. Eng. Chem. Res.,* 42 (25): 6641-6646.

Saldana MDA., Temelli F., Guigard SE., Tomberli B., Gray CG. 2010. Apparent solubility of lycopene and β-carotene in supercritical CO_2, CO_2+ethanol, and CO_2+canola oil using dynamic extraction of tomatoes. *J. Food Eng.,* 99 (1): 1-8.

Shi, J., Yi C., Xue SJ., Jiang Y., Ma Y., Li D. 2009a. Effects of modifiers on the profile of lycopene extracted from tomato skins by supercritical CO_2. *J. Food Eng.,* 93 (4): 431-436.

Shi, J., Khatri M., Xue SJ., Mittal GS., Ma Y., Li D. 2009b. Solubility of lycopene in supercritical CO_2 fluid as affected by temperature and pressure. *Sep.Purif. Technol.,* 66 (2): 322-328.

Stadtman, ER. 1992. Protein oxidation and aging. *Science,* 257 (5074): 1220-1224.

Stahl, W., Sies, H. 1996. Lycopene: A Biologically Important Carotenoid for Humans?. *Arch. Biochem. Biophys.,* 336 (1): 1-9.

Topal, U., Sasaki M., Goto M., Hayakawa, K. 2006. Extraction of Lycopene from Tomato Skin with Supercritical Carbon Dioxide: Effect of Operating Conditions and Solubility Analysis. *J. Agri. Food Chem.,* 54 (15): 5604-5610.

Vagi, E., Simandi B., Vasarhelyine, KP., Daood, H., Kery, A., Doleschall, F., Nagy, B. 2007. Supercritical carbon dioxide extraction of carotenoids, tocopherols and sitosterols from industrial tomato by products. *J. Supercrit. Fluid.,* 40 (2): 218-226.

Vasapollo, G., Longo, L., Rescio, L., Ciurlia, L. 2004. Innovative supercritical CO_2 extraction of lycopene from tomato in the presence of vegetable oil as co-solvent. *J. Supercrit. Fluid.,* 29 (1-2): 87-96.

Yi, C., Shi, J., Xue SJ., Jiang, Y., Li, D. 2009. Effects of supercritical fluid extraction parameters on lycopene yield and antioxidant activity. *Food Chem.,* 113 (4): 1088-1094.