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Processing tomato pulp in the presence of lipids: The impact on lycopene bioaccessibility

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ABSTRACT

Industrial processing of tomatoes into different end-products includes mechanical treatments, several thermal treatment steps, and the addition of ingredients which might induce changes in lycopene bioaccessibility. Here the influence of high pressure homogenisation (HPH) (100 bar) and microwave heating (20 min at 70, 90, and 120 °C) of tomato pulp was evaluated in the absence and in the presence of three different oils (5%) with distinct fatty acid composition (coconut oil, olive oil, and fish oil). Lycopene bioaccessibility in the processed samples was studied by quantifying the fraction of lycopene that was transferred from the food matrix to the aqueous micellar phase during *in vitro* digestion.

Adding lipids prior to processing clearly enhanced the lycopene bioaccessibility. However, the type of lipid added was of minor importance compared to the process conditions applied. HPH or microwave heating of tomato pulp in the presence of lipids during 20 min at 70 and 90 °C did not improve the lycopene bioaccessibility significantly. When HPH was applied prior to the heat treatment, microwave heating at 90 °C could improve the lycopene bioaccessibility. It is hypothesised that HPH damages the cellular barriers for lycopene bioaccessibility, which can be further disrupted by thermal processing improving lycopene release during digestion. Finally, applying conditions of 20 min at 120 °C as such facilitated the lycopene bioaccessibility remarkably. HPH preceding this thermal treatment was of no extra value in terms of lycopene bioaccessibility.

1. Introduction

Cardiovascular diseases, cancer, obesity, and diabetes are the main mortality causes in Europe and other Western countries. An unhealthy diet is, next to the lack of physical activity, tobacco and alcohol use, one of the major risk factors for these chronic diseases (WHO, 2009). Fruit and vegetables are important components of a healthy diet. Approximately 1.7 million of deaths worldwide (2.8%) are attributable to low fruit and vegetable consumption. Moreover, insufficient intake of fruit and vegetables is estimated to cause around 14% of gastrointestinal cancer deaths, about 11% of ischemic heart disease deaths, and about 9% of stroke deaths (WHO, 2002). Eating a variety of vegetables and fruits ensures an adequate intake of most micronutrients, dietary fibres, and essential non-nutrient substances. The WHO recommends a minimum daily intake of 400 g of fruits and vegetables (WHO, 2003) in the context of the prevention of chronic diseases. However, this recommended consumption level is only met by a limited number of populations (EUFIC, 2012). Therefore there is a need for concrete action to increase the consumption of these commodities. Since consumer demands for ready-to-eat foods continues to increase in developed countries, more attractive convenience foods with a high content of bioavailable micronutrients may contribute. Therefore, the food manufacturer is faced with the challenge of increasing the bioavailable micronutrient content, while maintaining a safe product with acceptable organoleptic properties.

In this perspective, research in this work focused on lycopene, a carotenoid with potential health benefits (Kun, Lule, & Xiao-Lin, 2006), mainly found in tomatoes (Bramley, 2000). Industrial processing of tomatoes into different end-products like juice, soup and sauce, includes mechanical treatments, several thermal treatment steps, and the addition of other ingredients which might induce either desirable or undesirable quality changes. Optimisation of the process conditions and product formulation may improve the nutritional and functional value of the processed tomato products. Because it is only useful to create tomato products with high lycopene content if the lycopene present is absorbable by the human body (= bioaccessible), it is important to have profound insight into the impact of processing and product formulation on the bioaccessibility of lycopene.

Both mechanical and thermal processing can affect the tomato cellular matrix in which lycopene is embedded and therefore processing may be an important factor influencing lycopene bioaccessibility in tomato derived food products (Parada & Aguilera, 2007; Van

Abbreviations: HPH, high pressure homogenisation; PSD, particle size distribution.

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Buggenhout et al., 2010, 2012). In this context some work has been done in recent years and has shown that the effect of processing is more complex than might be expected intuitively. Only a few studies have focused on the impact of mechanical tomato processing, as such. Tiback et al. (2009) reported that using ultra-high-speed homogenisation could not increase the release of lycopene during *in vitro* digestion of crushed tomatoes. Colle, Van Buggenhout, Van Loey, and Hendrickx (2010) subjected plain tomato pulp to high pressure homogenisation (HPH) at pressures ranging from 0 to 1300 bar. Although HPH clearly disrupted the cellular structure of the tomato pulp, a decreasing trend of lycopene bioaccessibility with increasing pressure was observed. Similarly, the progressive loss of cell integrity, observed with increasing time of ultrasonication, was accompanied by a decrease in lycopene bioaccessibility (Anese, Mirolo, Beraldo, & Lippe, 2013). In the study of Svelander, Lopez-Sanchez, Pudney, Schumm, and Alminger (2011), a heated 5% olive oil/tomato emulsion was homogenised at 100 bar and 1000 bar. No change in lycopene bioaccessibility was noticed after HPH. Also controversial results regarding the impact of heat on lycopene bioaccessibility can be found in literature. No effect of domestic boiling, grilling, microwave-cooking, or steaming of quartered tomatoes was found on the lycopene bioaccessibility (Ryan, O'Connell, O'Sullivan, Aherne, & O'Brien, 2008). However, thermal processing as such could increase the lycopene bioaccessibility of plain tomato pulp but only significantly when temperatures above 120 °C were applied (Colle, Lemmens, Van Buggenhout, Van Loey, & Hendrickx, 2010). When heating was preceded by long duration crushing (120 s), less intensive heat treatments (blanching at 60 °C and 90 °C (Svelander et al., 2010), 8 min at 95 °C, and 20 min at 100 °C (Tiback et al., 2009)) caused a significant increase of lycopene bioaccessibility. Recent research also showed that extrusion cooking, involving severe mechanical and heat processing treatments, improved the bioaccessibility of lycopene from tomato derivatives which partially replaced corn grits in snacks (Dehghan-Shoar, Mandimika, Hardacre, Reynolds, & Brennan, 2011).

Most tomato derived food products like soup and sauces contain next to tomatoes other ingredients including lipids. Ingestion of fat along with carotenoids is thought to enhance the absorption of carotenoids (Castenmiller & West, 1998; van het Hof, West, Weststrate, & Hautvast, 2000; Yeum & Russell, 2002; Yonekura & Nagao, 2007). Carotenoid uptake follows the same digestive route as lipids and they need to be incorporated into micelles to be absorbable (Borel, 2003). Next to bile salts and biliary phospholipids, mixed micelles contain free fatty acids and monoglycerides resulting from hydrolysis of triglycerides (Yonekura & Nagao, 2007). Therefore ingestion of fat along with carotenoids is thought to be crucial for the absorption of carotenoids (van het Hof et al., 2000). Some recent studies indicated that lipids can positively influence the lycopene bioaccessibility. After the *in vitro* digestion of a salad puree (Huo, Ferruzzi, Schwartz, & Failla, 2007), a meal containing courgette, red pepper, and spinach (O'Connell, Ryan, O'Sullivan, Aherne-Bruce, & O'Brien, 2008) or tomato pulp (Colle, Van Buggenhout, Lemmens, Van Loey, & Hendrickx, 2012) a significantly enhanced micellarisation of lycopene was found in the presence of different kinds of lipids. Moreover, it has been suggested that lycopene bioaccessibility increases more by consuming long chain triglycerides than when short/medium chain triglycerides are ingested (Colle et al., 2012; Huo et al., 2007).

The question that remains is whether the presence of different types of lipids during tomato processing results in different lycopene bioaccessibilities. To elucidate this and to further investigate the effect of mechanical and thermal processing both HPH and microwave heating of tomato pulp was performed in the absence and the presence of 5% coconut oil, olive oil, and fish oil. Lycopene bioaccessibility was studied by quantifying the fraction of lycopene that was transferred from the food matrix to the aqueous micellar phase during *in vitro* digestion.

2. Materials and methods

2.1. Materials

Coconut oil, olive oil, and fish oil were selected because of their different fatty acid composition (Table 1). They were donated by Vandemoortele (Gent, Belgium). The fatty acid composition of the coconut and olive oil was given by the supplier and the fatty acid composition of the fish oil was determined by gas chromatography following fatty acid methylation according to the method described by Ryckebosch, Muylaert, and Foubert (2011). None of the lipids contained lycopene (analysed using RP-HPLC). Red ripe tomatoes (*Solanum lycopersicum* L., cultivar Patrona) were harvested in Spain in 2010. They were washed, dried, quartered, frozen in liquid nitrogen, and stored at −40 °C. Upon use, a tomato pulp free from seeds and skin was prepared by thawing, blending (3 times 5 s) (Büchi Mixer B-400, Flawil, Switserland), and sieving (pore size 1.0 mm) the tomato quarters. All chemicals and reagents used were of analytical or HPLC grade.

2.2. Experimental set-up

A schematic overview of the experimental set-up is presented in Fig. 1. The effect of processing in the absence and in the presence of 5% of the selected lipids (coconut oil, olive oil, and fish oil) was investigated. The processing conditions included HPH at 100 bar (see Section 2.3) or microwave heating (see Section 2.4) during 20 min at 70, 90, and 120 °C. In addition, HPH at 100 bar was followed by microwave heating at the three different temperatures. All processes were performed in quadruple. An aliquot of each sample was frozen in liquid nitrogen and stored at −80 °C until lycopene content determination. The lycopene bioaccessibility was measured immediately after processing. The particle size distribution measurement (see Section 2.7) and the microscopic investigation (see Section 2.8) of the high pressure homogenised samples were performed after limited storage at 4 °C. For each condition a separate batch of tomato pulp was prepared and a control sample which did not contain added lipids and which was not processed was analysed.

2.3. High pressure homogenisation

The homogeniser (Panda 2 K, Gea Niro Soavi, Mechelen, Belgium) used was equipped with two homogeniser valves with a spherical

Table 1
Fatty acid composition of lipids used.

Fatty acid (%)	Coconut oil	Olive oil	Fish oil
C8:0	7.0	nd	0.0
C10:0	6.0	nd	0.0
C12:0	46.0	0.0	0.0
C14:0	19.0	0.0	5.6
C16:0	9.0	11.4	15.4
C16:1	nd	nd	5.4
C18:0	3.0	2.9	3.3
C18:1	7.5	74.4	13.9
C18:2	2.0	8.9	1.6
C18:3	nd	0.6	1.0
C20:0	nd	0.5	1.8
C20:1	nd	0.3	5.3
C20:5	nd	nd	9.4
C22:0	nd	0.2	1.4
C22:1	nd	nd	3.9
C22:6	nd	nd	13.5
others	0.5	0.8	18.5
saturated	90.0	15.0	27.5
mono-unsaturated	7.5	74.7	28.5
poly-unsaturated	2.0	9.5	25.5

nd: not determined.