Tomato - Characteristics, Processing and Future Trends in Automation for Smallholder Processing Industry: A Short Review

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ABSTRACT Tomato is one of a globally important warm-season vegetable crop. Overall, the whole fruit is edible. It contains sorbitol, phenylalanine, putrescine and vitamins such as B_1, B_2, and B_3. Tomato also contains carotenoids such as α-carotene, β-carotene, lycopene, and xanthophylls. In addition, they also contain phytosterol, essential oils (terpenes geraniol and farnesol), flavonoids (quercetin, kaempferol, and isorhamnetin) and alkaloids (saponins). Since the processing of tomatoes affecting the content of nutrients, it is important to understand the details on how tomatoes are being processed. Tomato farming in Malaysia is mainly concentrated in the highlands. Kundasang, Sabah is one of the few areas where smallholder-farming tomatoes are planted due to its suitable environment and temperature. Although tomatoes from smallholder farmers are usually for direct consumption, stockpiling occurred recently due to movement-controlled order enforced in Malaysia to control COVID-19 transmission, affecting the livelihood of smallholder farmers in Kundasang mainly due to logistics issues. Therefore, the purpose of this paper is to review on tomato, its nutrients content, and processing technology giving importance on aspect of nutrient retention by monitoring and controlling process parameters using low-cost IoT-based automation and its future directions for smallholder tomato farmers.

KEYWORDS: Automation; IoT; Processing; Smallholder farmers; Tomatoes
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Review Article

INTRODUCTION

Tomato (*Lycopersicon esculentum* L) is an important vegetable, globally due to its quality and quantity (Motamedzadegan & Tabarestani, 2018). Tomato is a warm-season crop and it belongs in the Solanaceae family. For an optimal growth, it requires temperature of 25–30 °C and 16–20 °C for day and night, respectively (Garg & Cheema, 2011). To obtain the best fruits, the temperature should be maintained at 18–24°C, where the night temperature is more critical compared to the day temperatures. Figure 1 shows anatomy of a tomato composed of fruits and fruiting bodies.

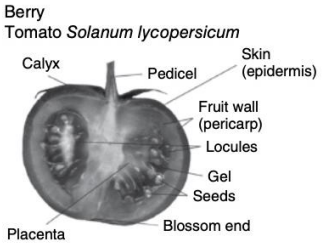

Figure 1. Anatomy of a tomato (Radovich, 2018)

In 2014, the global total production of tomato was 170.8 million metric tons. In which was an increase by 3.24-fold since 1980. The production is led by China (30.80%), India (10.97%), USA (8.50%), Turkey (6.94%) and Egypt (4.85%) (Food and Agriculture Organization (FAO), 2016).

The major exporting and importer countries in 2013 were Netherlands, Jordan, Mexico, Spain, and USA; and Turkey, Germany, Russian Federation, the United Kingdom and France (Food and Agriculture Organization (FAO), 2017). Due to their nutritional and organoleptic properties, tomatoes are consumed as a raw food. Apart from that tomatoes are processed to become paste, soup, ketchup, canned tomatoes, juice, purée and sauce (Motamedzadegan & Tabarestani, 2018). Since the processing of tomatoes effect these properties, it is important to understand the details of tomatoes processing.

An extensive discussion on vegetable and vegetable processing has been prepared by Butt & Sultan, 2018; Motamedzadegan & Tabarestani, 2018; Ong & Liu, 2018; Radovich, 2018, and compiled in Siddiq & Uebersax, 2018. Some key point on vegetable and vegetable processing are reiterate in this paper to focus to tomato and tomato processing giving importance to issues and future directions for smallholder tomato farmers.

FLAVOR AND SENSORY CHARACTERISTICS

Among, significant compound for aroma of fresh tomatoes are hexanal, 3-methylbutanal, (E)-hexenal, (Z)-3-hexenal, 1-hexanol,(Z)-3-hexenol, 3-methylbutanol, 1-penten-3-one, β-ionone, 6-methyl-5-hepten-2-one, β-dama- scenone, methyl salicylate, 2-phenylethanol, furaneol, guaiacol, benzyl alcohol, dimethyl sulfide, 2-sec-butylthiazole, and 2-isobutylthia- zole (Du *et al*., 2015; Ortiz-Serrano & Gil, 2007; Selli *et al*., 2014).

The key difference between the flavour of processed and fresh tomato is the near complete loss of cis-3-hexenal and the presence of furfural (Marković *et al*., 2007). Based on genotype and environment, glucose and fructose and citric acid and their ratio largely determine the taste of tomatoes (Cebolla-Cornejo *et al*., 2011). While, the glutathione enhancing the flavour and mouthfeel perception (Ueda *et al*., 1997).

Enzymes lipoxygenase influence the colour, flavour, and texture of fresh-cut tomatoes, by catalysing the oxidation of polyunsaturated fatty acids to form C_6 to C_9 which are volatile aldehydes, together with "grassy" therefore "grassy" flavour notes. These breakdowns the pectins, creating in tissue softening and eventually lead to loss of firmness (Ong & Liu, 2018).

NUTRITIONAL PROFILE

Tomatoes have more than 90% moisture, which is 10 % higher than most vegetables. The content of carbohydrates, protein, fat and dietary fibre are 3.92, 0.88, 0.20, 4.1 and 18 g respectively (U.S. Department of Agriculture (USDA), 2016). Tomatoes contained the least stable vitamin C, often destroys due to its heat labile nature and light exposure (Siddiq & Uebersax, 2018). The content of Ascorbic Acid, Carotenoids, Thiamine, Riboflavin, Niacin, Calcium, Iron and Folic Acid for tomatoes are 19-48, 0.19-1.45, 0.04-0.11, 0.02-0.12, 5, 5-14 and 0.4-1.0 (mg) and 0.45-0.91(µg), respectively (U.S. Department of Agriculture (USDA), 2016).

Hydroxycinnamic acids, such as caffeic, p-coumaric, sinapic, ferulic, and chlorogenic acids (Anterola & Lewis, 2002) are located at the pericarp of the tomato. Compound such as rutin, naringenin chalcone and kaempferol-3-O-rutinoside, are the flavonoids in tomatoes (Crozier *et al*., 1997; Long *et al*., 2006; Muir *et al*., 2001). The mineral contents (mg/100 g) of tomatoes for Ca, Fe, Mg, P, K, Na, Zn, Cu and Mn are 30, 0.3, 11, 27, 191, 67, 0.27, 0.085 and 0.134 respectively (U.S. Department of Agriculture (USDA), 2016). Lycopene in tomato is a strong antioxidants, lowers cholesterol, lowers glucose and has anticancer potential (Butt & Sultan, 2018). Apart from lycopene, tomato also contain

other carotenoids such as α-, β-, γ-, and ζ-carotene, lutein, zeaxanthin, α- and β-cryptoxanthin, violaxanthin, neoxanthin, neurosporene, phytoene, phytofluene, cyclolycopene, and β-carotene 5,6-epoxide (Burns *et al.*, 2003; Fraser *et al.*, 1994; Heinonen *et al.*, 1989; Khachik *et al.*, 2002).

Tomatoes contain glycoalkaloid, which is α-tomatine. Glycoalkaloids shows the ability in antibacterial effects (Gubarev *et al.*, 1998), inactivate herpes simplex virus (Thorne *et al.*, 1985), enhancement of general anesthetics to inhibit cholinesterase (McGehee *et al.*, 2000), lowering of plasma chlesterol in hamsters (Friedman *et al.*, 2000), potentiation of a malaria vaccine (Heal *et al.*, 2001), and inhibition of the growth of liver and human colon cancer cells (Lee *et al.*, 2004).

TOMATO PROCESSING

The food processing technology involve a series of process including, canning, freezing, cooking, microwaving, drying, pasteurization, freeze-drying, concentration and smoking. There are also alternative technology, such as UV light, radio frequency, pulsed electric field, irradiation pulsed light, ozone, ohmic heating, electromagnetic and high pressure processing to increase the safety, quality, and shelf-life of vegetables thus meeting the increasing consumer demand (Siddiq & Uebersax, 2018).

Normally, processing of food decreases the nutritional value due to the reduction of compounds (Klopotek *et al.*, 2005). Unit operation introduce air or heat treatment into juices will expedite oxidation of ascorbic acid, therefore, create the need for fast reduction in temperature (Motamedzadegan & Tabarestani, 2018).

It has been reported that lycopene is highly available in processed tomato in contrast to in raw tomatoes (Gartner *et al.*, 1997). Lycopene is also stable to heat treatment and storage (Motamedzadegan & Tabarestani, 2018). The degradation of lycopene may due to high temperature, exposure to oxygen, and low water activity (Leoni, 2002). During handling, most lycopene may be converted from the all-trans form into the less bioactive, cis isomer (Muratore *et al.*, 2008), which can be contributed by the processes involved in the production of sauces, soups, and juice (Gartner et al., 1997).

The content of total phenolic of tomato purée is decreased at high temperature and short time of 98°C and 40 seconds via pasteurization (Pérez-Conesa *et al.*, 2009). In contrast, an earlier study reported that by blanching at 100°C for 30 minutes, there are an increase of tomato phenolic in range of 23 – 34 % (Shen *et al.*, 2007). Therefore, there is a need to balance between temperature and duration of heat treatment for an optimum phenolic content.

Pre-processing unit operation for tomatoes includes, grading, washing, sorting and trimming, coring and peeling. Being a versatile vegetable, tomato able to be process to various products such as juice, paste, sauce, soup, ketchup, and canned tomatoes (Motamedzadegan & Tabarestani, 2018).

The processing for tomato puree and paste include break, extraction and refining of juice, concentrating (evaporation) and sterilization and packaging. For canned whole tomatoes, the process includes peeling, sorting and filling, additives, exhausting and sealing, thermal processing, and cooling, labelling and packing. For tomato juice, the important process includes crushing, breaking and extraction, deaeration, salting and filing, and homogenization and thermal processing (Motamedzadegan & Tabarestani, 2018).

For tomato ketchup, the important process includes crushing, breaking and pulping, as well as formulation, follow by cooking, finishing and homogenization and lastly, deaeration filling, sterilizing and cooling. For chilies sauce, the route almost similar using tomato as one of the ingredients (Motamedzadegan & Tabarestani, 2018).

Tomatoes also can be process as dried tomato products, by dehydration process. Additionally, tomato also can be turn into powder (Motamedzadegan & Tabarestani, 2018). The tomato powder is produced by increasing the concentration of tomato solids from 30 to 40% in tomato paste to about 97%. Tomato powder is prepared from tomato paste, which is prepared by hot-break method. Even though, there are various dryer such as roller drum-dryer, foam- mat dryer, the spray-dryer appears to be the most suitable to produce high quality powder.

Additionally, only small faction of tomatoes is frozen compared to other process. The process includes washed, sorted, blanched, peeled, sliced, diced, or left whole, inspected, and frozen on an individually quick-frozen belt freezer, via fluidization to −13 °C (Motamedzadegan & Tabarestani, 2018). However, frozen method was reported to be uneconomical (Barringer, 2004a). For easy reference, the flowchart on tomato processing for producing various tomato products is illustrated in Figure 2.

When tomato is processed, there will be by-product. It is called tomato pomace, which constitute of skin and seeds (lignocellulosic-based substrate). It can be used to produce pectins and vitamin B12 for human consumption as supplement and source of non-conventional oil. Lycopene, able to be recovered from waste of tomato paste, tomato pulp, and tomato processing. However, current technologies are uneconomical and has slow response (Motamedzadegan & Tabarestani, 2018). Organic waste should be minimized to not occupy landfill subsequently, reduce factors that induce climate change.

IMPLEMENTING AUTOMATION FOR MANUAL TOMATO COTTAGE PROCESSING

Following the fourth industrial revolution (IR 4.0), automation becoming a current trend in monitoring the production and delivery of products and services by reducing or without human intervention. It is expected that the total annual production of tomato in Malaysia increases in the year 2020 and beyond, as shown by the increased in value from 165k tonnes in 2015 to 176k tonnes in 2019 (Knoema 2020). As a market demand for tomato grows, productivity becomes a bigger concern for fulfilling the demand.

Smart agriculture has been widely discussed and implemented in the recent years (*Ardiansah et al.*, 2020; Kumar *et al.*, in press.; Nižetić *et al.*, 2020; Villa-Henriksen *et al.*, 2020), and have become key element in modern agriculture for helping producers with real-time monitoring and critical decision-making. However, smart farming or agriculture alone is insufficient for ensuring continuous productivity of tomato supply chain, starting from the crops to the finished products (tomato sauce, puree, juice, canned tomatoes etc.). Developing and implementing automation on the tomato processing line not just increases the productivity, but enables for efficient processing time with minimum labour, and produce products with standard quality (Nimawat & Shrivastava, 2016).

Monitoring the production process parameters variation is essential in order to determine the quality of a product, whether or not they meet the standard specifications. Some process parameters that can be automatized for tomato cottage processing industry including temperature, liquid level, flowrates, and pH. Low-cost automation using microcontroller is one of the feasible and widely

discuss IoT-based automation in the recent years, following the IR 4.0 concept. Many researches have conducted IoT-based automation study using microcontroller for different type of systems. For example, Firmansyah *et al.* (2020) developed an IoT based automation temperature control system for water heater using NodeMCU ESP8266 with integrated PI controller. Mardiyanto (2019) included pH sensor in their work on real-time plant process control monitoring system using microcontroller (Arduino Uno and AVR ATMega328). On the other hand, Sanjeev *et al.* (2019) constructed a system for chemical process surveillance using IoT and incorporated level parameter for monitoring chemical process parameter using IoT. They used an ultrasonic sensor HC-SR04 for measuring the level of the working fluid inside a tank. While for water flow, Hakim *et al*. (2018) used water flow sensor EGO-2 for measuring water flow in their project related to monitoring the water of flow consumed by household per month. The abovementioned control systems' successful implementation allows them to be implemented in the tomato cottage processing line, ensuring continuous productivity of tomato supply chain and producing products with consistent standard specifications.

QUALITY FOR PRODUCT PROCESSING

The quality aspects of tomato and tomato product, are divided into 1) criteria for fresh market and 2) product processing. Nutritional value, insecticides and fungicides, and organically status are important for consumer (Barringer, 2004b). For product processing, factor such as the color of the fresh produce associated with quality and freshness. The perception for tomato is the redder the tomato the better it is (Barringer, 2004b). The red colour is due to lycopene, in which its lost can be accelerated by high temperature and exposure to oxygen.

Viscosity is one of USDA's quality grade standards for ketchup and tomato sauce. Since the yields and quality influence by viscosity, it is also affecting the economics of the processors. The final viscosity is affected by temperature, size of finisher screen, milling, blade speed, and pulp preparation method. Viscosity may reduce at high temperature processing due to the pectin denatured (Motamedzadegan & Tabarestani, 2018; Siddiq & Uebersax, 2018). Tomato fruits has pH in the range of 4.0 - 4.5. A lower pH, indicated a greater tartness which is a criterion for consumer quality acceptance. Tomatoes need to be ensured to have a pH below 4.6, therefore able to be processed as foods of high-acid (Motamedzadegan & Tabarestani, 2018).

In terms of flavour, both processed tomatoes and fresh tomatoes have distinctively different aroma due to the loss of volatiles components of the fresh tomatoes during processing. This include cis-3-hexanal and hexanal (Buttery *et al.*, 1990). Degradation of flavour volatiles, inactivation of lipoxygenase and related enzymes can be caused by heating. The cause of formation of terpenes and terpene like compounds are due to oxidative decomposition of carotenoids. Cooked odour is due to the breakdown of sugars and carotenoids. The aroma of heated tomato products is highly influence by dimethyl sulphide. An off-flavour formed during heating is due to Pyrrolidone carboxylic acid (Barringer, 2004b).

In regards of tomato juice, serum separation is a major problem in tomato juice production. Here solids settle at the bottom of the solution, leaving a clear serum on top. A stable suspension of particles would have prevented this problem.

Yield and consistency of the finish product are affected by tomato solids, which is measured by total solids measurement. However, soluble solids are more frequently measured due to a more time-efficient measurement. This soluble solid are sugars and reach its peak on fully ripe tomatoes (Hobson & Grierson, 1993). This sugar also reduced during heating, due to caramelization, formation of 5-

hydroxymethyl furfural and Maillard reaction. As much as a 19% loss in processed tomato juice and a 5% loss during spray drying (Barringer, 2004b).

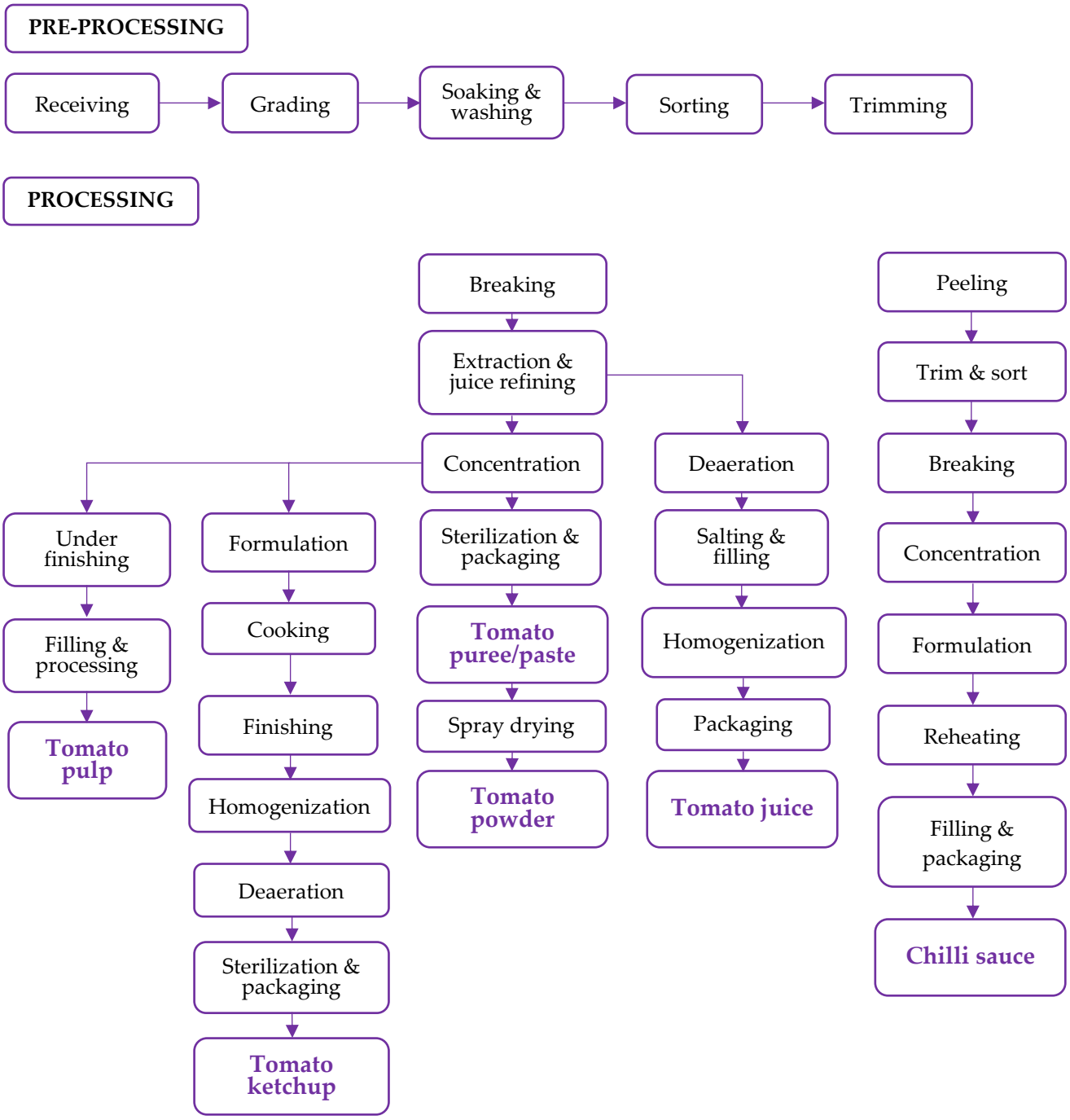

Figure 2. Pre-processing and processing flow diagram of various tomato products. Adapted from Motamedzadegan & Tabarestani (2018)

FUTURE DIRECTION FOR SMALLHOLDER FARMERS

Tomato production in Malaysia is mainly concentrated in the highlands. Kundasang is one of the few areas where tomatoes are planted due to its suitable environment and temperature (Rahim *et al.*, 2017). Stockpiling occurred due to movement-controlled order enforced in Malaysia to control COVID-19 transmission, create a need for tomatoes to be processed to extend their shelf life. The order which take effect between March – June 2020 followed by the second controlled movement order, starting October 7, 2020 (Majlis Keselamatan Negara (MKN), 2020). By processing the fresh tomato,

enable to secure the livelihood of smallholder farmers in Kundasang who are the most affected due to logistics issues (Ooi & Dambul, 2020).

Manual processing of fresh tomatoes, are time consuming, labour intensive and prone to produce products that are off-specification. An automated mechanized downstream processing system, enables for an efficient processing time, minimum labour, and produce products of standard quality. Since the volume of feedstock acquires from the smallholder farmers are expected to be small, it is a challenge to develop an energy efficient processing system for a small-scale production. Therefore, there is a need to create a processing system, which is energy efficient and automatized coupling with IR 4.0 elements.

CONCLUSION

This short review, has discuss on the tomato characteristics and its processing. The processing of tomatoes affects the content of nutrient therefore, it is important to understand on the options of tomato processing. The understanding on the tomato processing gives knowledge on ways to retain the nutrients by controlling certain process parameters. Manual processing is inefficient for controlling process parameters thus, producing products that are off-specification. IoT-based automation using low-cost microcontroller is economical feasible for smallholder tomato cottage processing industry. This therefore, give direction on future development for tomato processing for smallholder farmers.

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