Vol. 42(4), 2018

Post Harvest Value Chain of Carrot – A Review

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Date of submission: 15.02.2018 *Date of acceptance: 15.7.2018*

ABSTRACT

The abundance of nutritional components and bioactive compounds in carrot i.e. carotenoids, dietary fibre, anthocyanins, vitamin C and E creates its demand both in raw and processed forms e.g. carrot juices, pickles, candy, jam, dehydrated carrot powder, etc. The phytonutrients present in carrot - rich in carbon as well as fibre are used in production of paper and composite films. Carrot leaves can be utilised in production of soups and broths in powder form. Moreover, the by-product of carrot juice industry i.e. pomace/peel has the potential for production of dietary fibre rich polysaccharides, oligosaccharides and lignin along with biomass and bioethanol.

Keywords: *Carrot, Nutrition, Carrot processing, Carrot by-products*

INTRODUCTION

Carrot (*Daucus carota* L.) is one of the most important root crop *Apiaceae* families. It has been cultivated worldwide and enjoyed as fresh cut carrot products such as shredded, sliced, sticks or in the form of ready to eat processed products. The cultivation practices of carrot were initiated in Middle Asia (Punjab and Kashmir). India has 88 thousand ha area under cultivation of carrot with annual carrot production of 1379 thousand MT out of which Haryana shares 27.80% followed by Uttar Pradesh, Punjab and Tamil Nadu (Anon 2016). Cultivation of carrot has been carried out in different parts of world according to the climatic conditions such as in month of September to November in tropical and subtropical region whereas, temperate region have wide option of cultivation throughout the year (Raees-ul and Prasad, 2015). Well known group of carrot are as follows: Chantenay – Medium-sized, conical, stump-rooted types, late-maturing; Amsterdam forcing – Small to medium-sized, slender, cylindrical, stump-rooted types of good quality, early maturity; Nantes –Medium, cylindrical, stump-rooted types, medium maturity; Berlicum – Large-sized, cylindrical, stump-rooted types, late-maturing; Autumn King – Very large-sized, tapering rooted types, late-maturing and heavy-yielding.

Carrot is moderately hard, long and thin, cylindrical or spherical in shape and available in orange, orange-red, black and purple colour. It is not in rich of calories but a rich source of nutrition in the form of phytochemicals such as carotenoids, anthocyanins and other phenolic compounds. Carrot is rich source of vitamin A carotenoids of vegetal origin especially α and β carotene. Besides nutrition rich (Table 1) it is also popular for sweetness, antianemic, healing, diuretic and sedative properties. Increased consumption of the raw as well as processed carrot has increased worldwide. Jagtap *et al.*, (2000) have suggested that carrot pomace due to its high nutritional composition can also be utilized for the preparation of good quality toffees. As the black carrots have outstanding higher content of anthocyanins (up to 17.4 g/kg dry matter) (Kammerer *et al.*, 2004), it is a promising alternative to acidic foods such as soft drinks and confectionery (Wrolstad and Culver, 2012). The root of the carrot is widely consumed part of the crop, although in China and Japan, tender foliage has been used as a stir fried herbs and as a salad (Rubatzky *et al.*, 1999).

Table 1: Chemical composition of fresh carrot (Sharma *et al*., 2012)

Character	Composition (g/100g)	Character	Composition (g/100g)
Carbohydrates	10.6	Vitamin B_2	0.06
Protein	0.93	Vitamin B_3	0.93
Fibre	2.80	Vitamin B_6	0.138
Fat	0.2	Vitamin E	0.66
Total sugar	4.74	β-Carotene	0.08285
Vitamin C	5.9	α- Carotene	0.03477
Vitamin B_1	0.07		

Unit Operations in Carrot Processing

Unit operations involved in the primary processing of carrot includes cleaning, cutting, washing, packaging and storage (Ahvenainen, 2000). Carrots are then cut to remove leafy part and edible root is used for consumption as salad as well as in processed form. Development of various products such as juices, beverages, carrot candy, pickles etc. can make it available in off season whereas, by product of carrot processing i.e. pomace can be used for development of extruded product, bioethanol and fibre and utilization of carrot leaves for the extraction of minerals and nutrients. The details of trends in post harvest processing and by-product utilization of carrot is given in Fig 1.

Processing Line of Carrot

Washing: Washing is the first step of post harvest processing of carrot and is carried out with the aim to remove soil and debris as well as to lower product temperature and microbial load. It has been reported that machine washing of carrot resulted in increased sensory score for bitter taste (8%), after taste (4%) and flavour (7%) as well as earthy flavour (12%) (Seljasen *et al*., 2004). Use of chlorinated cold (4°C) or warm tap water (50°C) is a common pre-treatment provided for the washing of carrot that ensures the microbial safety with improved sensorial properties (Klaiber *et al*., 2005). Hypochlorite solution containing 50-200 ml/l chlorine concentration has been followed for the contact time of 5 minutes (Francis and O'Beirne, 2002). Recent studies suggested that application of ozone instead of citric acid could reduce the water consumption in washing of vegetables (O¨lmez and Sa¨Rkka¨-Tikkonen, 2008). The batch type carrot washing machine was designed by Oyeleke (2014) as shown in Fig 2, in which carrots are fed into the washing chamber through the fruit hopper. The sprinklers spray water on the crop at high pressure spray across and along the conveying belt while travelling through the conveyor belt at a controlled speed. This is to ensure that the carrots are thoroughly cleaned

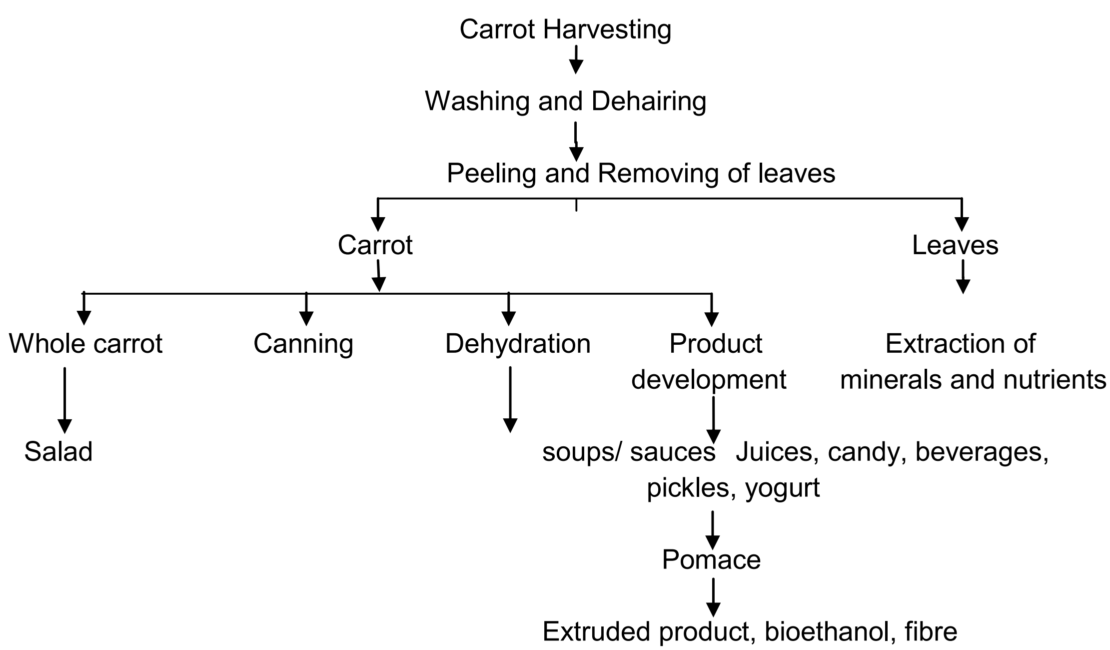

Fig. 1: Trends in post harvest processing of carrot

to the required standard. The machine was powered by a 0.75 kW single phase geared electric motor of 200 rpm with a power transmission efficiency of 90%.

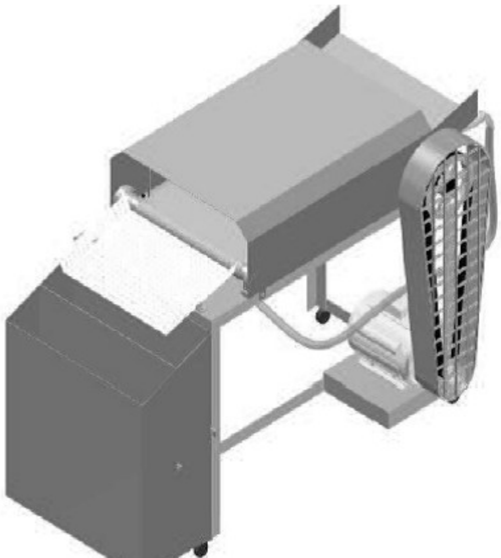

Fig. 2: Computer aided design of small scale carrot washer (Oyeleke, 2014)

Storage of carrot: After harvesting, garden vegetables are more likely to lose their physical and organoleptic properties under ambient storage conditions (Caron *et al*., 2003). Washed carrots are sorted and stored in cold stores at 0-10°C and 95-98% relative humidity so as to reduce the metabolic rate of harvested carrot and needs to be monitored to maintain low storage temperature (Afek *et al*., 1999; Eshel *et al*., 2009). Carrot is the high moisture crop (85-90%) and large part of it is lost through transpiration. It has been noted that quality of the carrot can be retained by application of cold storage, post harvest treatment and chemical applications (Ilić *et al*., 2009). Ozone having tri-atomic oxygen, is powerful oxidant and used for pest disinfestations and removal of mycotoxin and other contaminants from fruits and vegetables. Ozone applied as gas (0-5 mg/L) prevented the increase in the soluble solid content for 5 days when stored at (18 ± 2°C, 80 ± 5% RH) without loss in mass, firmness and colour (Souza *et al*., 2018).Moreover, carrot slices coated with low methoxyl pectin (0.75%) extended the shelf life up to 12 days during refrigerated storage with nearly three-fold lower accumulation of phenolic acids, responsible for white blush formation and seven-fold lower flavonoid content, responsible for astringency and bitterness in fresh-cut carrot slices (Ranjitha *et al*., 2017).

Peeling: Removal of peel and green part decreased the bitter tasting falcarindiol in carrot puree by 50% (Czepa and Hofmann, 2004). However, peeling may increase respiration rate, microbial contamination and the pH level (Barry-Ryan and O'Beirne, 2000). Peeling can be accomplished by rubbing/brushing or cutting operation. Washing and peeling should be done just before processing to prevent the development of off flavour to the carrot (Barry-Ryan and O'Beirne D, 2000).

Blanching: Blanching is an important thermal unit operation applied before freezing, pureeing, or dehydration of fruits and vegetables. This treatment can stabilize stored carrots by inactivating enzymes such as polyphenoloxidases, peroxidase, lipoxygenase, and phenolase whose activities lead to deteriorative reactions or nutritional decline (Gonçalves *et al.*, 2010). Cooking carrots in hot water from 70°C to 90°C within 1.4–25 min can reduce 90% of original peroxidase activity. However, to maximize quality, blanching at 80°C for 6 min is suggested (Gonçalves *et al.,* 2010). Blanching increased antioxidant activities of the roots significantly by an average of 34.3% as compared to those unblanched (Talcott and Howard 2000). Nonetheless, extending blanching time can lead to increased leaching of total carotenoids from the treated products. Blanching has also been demonstrated to significantly decrease lightness and chroma values of stained carrot color (Talcott and Howard 2000).

Steaming: Mechanical processing of modified atmosphere packed carrots may cause surface discoloration, normally associated with increased soluble phenolics, lignin, and enzymatic activities. Steaming is an ideal treatment to inactivate enzymes responsible for surface discoloration, without affecting colour, flavour, and texture of the product (Howard *et al.,* 1994). Steaming retards phenylalanine ammonia-lyase, peroxidase and phenylpropanoid metabolism, isocoumarin production, and lignin formation during storage at 2°C. Enzyme inactivation may also be effective to prevent the development of bitterness during the storage of the roots. Although steaming does not reduce bitterness of the roots during cooking, this treatment is reportedly an effective hydrothermal process to maintain the sweet taste of the roots (Borowska *et al.,* 2004). The taste, uniformity, and intensity of carrot orange color vary considerably with hydrothermal treatments. The physical properties such as force and energy of extrusion and the extrudability index depend on both carrot varieties and hydrothermal conditions (Borowska *et al.,* 2004). Additionally, steam treatment is also used as an effective method to reduce carrot rot during storage (Afek *et al.*, 1999). In one study, steam-treated carrot had only 2% root decay as compared to 23% in untreated samples. Similarly, fungi-inoculated carrots treated by steaming suffered a marginal 5% deterioration as compared to 65% observed in control samples (Afek *et al.*, 1999).

Product Development

Traditionally, carrots are processed in to different products, i.e. canned, dehydrated and powdered, pickles and intermediate moisture *halwa*. Increased awareness regarding benefits of carrot has created wide scope for development of value added products such as carrot yogurt, candy, jam and ready to serve juices.

Canned carrot: Usually small, tender and firm carrots are used for canning. Canning can be done in various forms such as diced, halved, quartered or as a whole. Blanching treatment to the sliced carrot at 71°C for 6 to 8 minutes results in better quality of canned product. In order to improve the colour and quality, carrots were treated thermally which caused increase in the amount of carotenoids in the products (De Sa and Rodriguez-Amaya, 2004). Cooking of carrots resulted in breakdown of cell wall membrane by partially dissolving cellulose thickened cell wall and by freeing of the nutrients. Various studies reported that leaching of the soluble solids during blanching is the most responsible factor that causes the increase of carotenoids (Sulaeman *et al*., 2001; Puuponen-Pimia *et al*., 2003). It was reported that blanched pre-treated dried carrot contains higher β-carotene with reduction of ascorbic acid content in comparison to unblanched dried carrot. Blanching treatment also prevents the non-enzymatic browning of carrot (Negi and Roy, 2001).

Dehydrated carrot: Widely used dehydration technique is convective drying with hot air at 40-60°C. However, prolonged drying time and overheating of the product resulted in brownish colour, loss of flavour and decrease in rehydration ability (Giri and Prasad, 2007). Blanching pre-treatment in 5% sugar solution to shredded carrot prior to dehydration was reported to be better. Alam *et al*., (2013) reported that convective drying at 65°C temperature of citric acid blanched carrot was best among solar drying, sun drying and convective drying methods. The freeze drying has been the excellent tool not only for the retention of carotenoids (96-98%) but also the flavour and colour of carrot (Rodriguez-Amaya, 1997). Combination of vacuum and microwave drying minimizes the shrinkage during drying with lower breakdown of physical structure and higher porosity (Béttega *et al*., 2014). Ultrasonic drying improves the drying kinetics and emerged as the energy efficient technology. The ultrasound assisted vacuum drying of carrot reduced the drying time by three fold (140 min) compared to vacuum drying (340 min) alone at same drying temperature 75°C. Rehydration, colour and nutritional properties of dried carrot were more influenced by ultrasound assisted vacuum drying as compared to conventional drying methods (Chen *et al*., 2016). Dried carrot can be incorporated in the varieties of food products such as soups, sauces, healthy snacks and ready to eat meals. Detailed

Selection of carrots

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Washing and peeling

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Cutting into 0.3 cm cubes

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Water blanching (containing 0.2% potassium metabisulphite, 2% starch and 1% salt) at 92^{o}C for 3 min

↓

Dehydration (45-50^{o}C for 10-11 h)

↓

Grinding of cubes

↓

Sieving of powder

↓

Powder

Fig. 3: Steps in preparation of carrot powder

procedure for development of carrot powder is shown in Fig. 3.

Pickle: For the commercial production of pickle, sodium chloride (NaCl) brine or potassium meta bysulfite can be added to prevent the softening of the carrot as well as it acts as a preservative (Fernandes, 2000). Carrot can be incorporated with brinjal and chilli. Generally, lactic acid has been used for the fermentation of carrot. It has been reported that pickles are good appetiser and add the palatability of meal (Sultana *et al*., 2014).

Juice: Pure carrot juice and its blends in different juices such as orange juice, pineapple juice has been most popular among the non-alcoholic beverages as well as formation of yogurt. Carrot juice has been extracted by pressing (Fig. 4). It has been reported that squeezing of blanched carrot mash produced higher yield of juice and carotenoids as compared to cold squeezing. Grinding of carrot in particle size from 6 to 2 mm increased yield by 0.7% per mm and also improved colour of juice for blanched and macerated carrots (Bin-Lim and Kyung-Jwa, 1996). Carrot juice is the rich source of α and β carotene. In order to reduce the bitterness of kinnow, mandarin juice, carrot juice incorporation has been a great option. Salwa *et al*., (2004) have incorporated carrot juice at the concentration of 5-20% in milk and prepared excellent quality carrot yogurt. Carrot juice has a shelf life of up to 4 days at 4°C temperature. In order to preserve the juice for longer time, some newer techniques such as ozone processing, ultrasound treatment (US), high pressure (HP) and ultraviolet treatments have been employed (Adiamo *et al.,* 2018). Riganakos *et al*., (2017) reported that shelf life of UV treated carrot juice was increased up to 12 days with no significant change in physicochemical and sensory characteristic of the juice stored at 4°C temperature. Different types of juice making equipment used in carrot juice extraction are as given below:

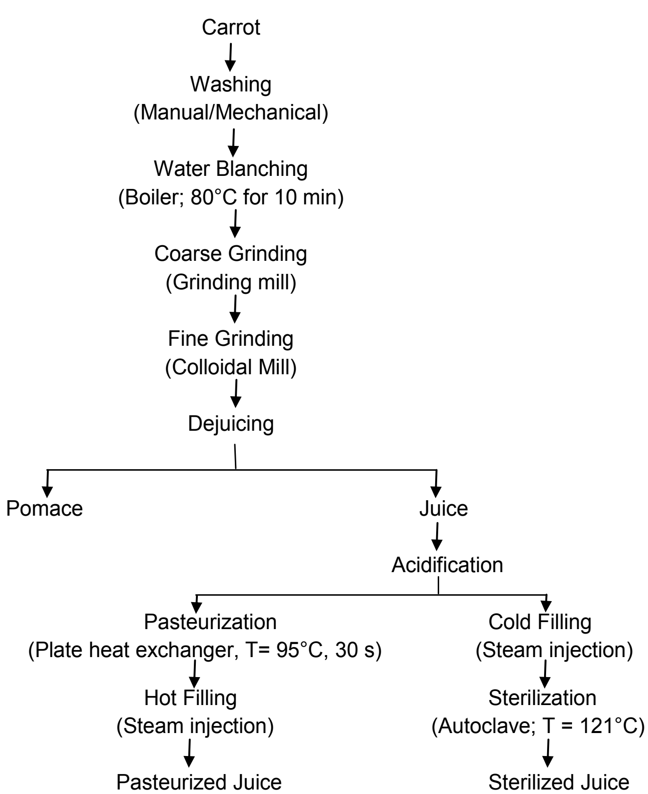

Fig. 4: Process flow chart for carrot juice production

i) Brush type carrot washing cum peeling machine: Brush type cleaning and washing machine is a horizontal cleaning cum peeling machine integrating the functions of washing, removing hair and mud and peeling as shown in Fig. 5. The machine has specially designed working brush having thorough cleaning and peeling effect without damage to carrots. Machine is composed of motor, conveying device, 8-15 brush roller spray device and washing tank. The machine is equipped with automatic spray device to help final washing, peeling and separating the sediments.

ii) Screw type juice extractor: The screw juice extractor machine is equipped with the screw and perforated screen assembly. Thus the juice extractor

Fig. 5: Brush type carrot washing cum peeling machine

does two function i.e. crushing and juicing. Raw material is fed into the feeding hopper and spirally pushed by screw. As the volume of helical cavity reduces, material is pressed by the boosting of the spiral. Thus, the juice and waste get separated by the juice extractor and discharged respectively. The pressure for extraction can be adjusted in the pressure plate assembly. The machine has flexibility of applications in juice extraction of fruits like apple, pineapple, orange, pomegranate, spinach etc.

Carrot candy: Preserve or carrot candy is the sweet food product prepared by immersing the carrot in the sugar syrup followed by draining off the excessive sugar syrup and drying to the stable state (Haq Raees-ul and Prasad, 2015). Beerh *et al*., (1984) have reported that the total soluble solid content of the carrot candy should be 70-75°B. An attempt was made to develop a honey based carrot candy and concluded that candy prepared at 1000:750 was found to have better sensory attributes when stored in glass and LDPE packaging materials. The product stored at low temperature (1-3°C) stored in glass container retains β carotene up to 60% and can be served for 6 months (Sharma *et al*., 2012).

Jam: Jam is prepared from boiling of pulp with predetermined quantity of sugar and pectin till the jel structured final product of low pH is formed. Although jam production is favoured for fruits, researchers have made successful attempts to extend it to some vegetables like tomato, cucumber, pumpkin, sweet potato and carrot (Haq Raees-ul and Prasad, 2015). In modified methods of jam preparation, carrot juice is added with citrus juice to prevent carotene oxidation. The mixture is cooked with sugar with addition of lemon juice and pectin for the proper gel formation. The method is widely preferable as it retains the most of the original compounds like phenolics, carotene, and potassium as well as colour attributes (Renna *et al*., 2013). Black carrot juice has also been incorporated as a colouring agent in manufacturing of strawberry jam by Kirca *et al*., (2007).

Composite film: Dried carrot residues have been reported to contain cellulose (81%), hemicelluloses (9%), pectin (7.5%) and lignin (2.5%). The phytonutrient of carrot include carbon and fibre which is used for the material development such as composite films. Edible films composed by loading fibres of vegetable origin such as fruit puree or cellulose modify the mechanical and barrier properties the film that allow water vapour transmission but act as a good barrier to gases. Iahnke *et al*., (2015) developed a biodegradable film from residue of gelatine capsule and minimally processed carrot. Carrot fibre film had beneficial effect on water content, water solubility and water vapour permeability, whereas gelatine based film demonstrated greatest tensile strength. Idrovo Encalada *et al*., (2016) tried to identify the effect of particle size and recorded that 53μm carrot fibre showed lowest hydration capability, highest water immobilization and highest stability when films stored at 57.7% RH and 25°C temperature. Cellulosic nano-fibres of diameter 2-30 nm and length of up to several micrometers are embedded in the hemicellulose and pectin matrix (Sharma *et al*., 2012; Bhatanagar and Sain 2005). Cellulose nanofibre present a very high stiffness of 130GPa and strength of 7-8GPa. Siqueira *et al*., (2016) explored the possibilities of isolation of nano fibre from carrot and their utilization in development of composite film. It was observed that nano fibre extraction from the carrot is more energy efficient compared to other raw materials. The elastic modulus and maximum strength of carrot nano fibre were in the range of 12.2-13.3 GPa and 204-243 GPa.

Activated carbon: Bastami and Entezari (2012) developed carrot dross based activated carbon (Fig. 6). Dried carrot dross was cleaned with water to remove dust and dried at 100°C overnight and finally grinded. Powder was treated with diluted nitric acid to extract soluble organic compound and functional group was introduced on the surface of raw material. The carbonisation of raw material was done at 500°C under air atmosphere for 1 h. Activated carbon was magnetised by mixing with diluted Fe_3O_4 sol at the proportion of 1/8 and 1/5 respectively. Activated carbon or magnetised activated carbon 0.2 g at pH = 4.0±0.5 and temperature 24±1°C was used for removal of PNP of various initial concentration (50-1200mg/L) in the presence and absence of ultrasound. The maximum adsorption capacity was found at highest sorbet concentration in presence of ultrasound and decreased with decrease in initial concentration. Changmai *et al*., (2017) developed the adsorbent from carrot, tomato and polyethylene terephthalate (PET) waste to remove Cobalt (Co II) from the aqueous solution. Adsorption technique improved efficiency of removal of undesirable metallic substances from the waste water and act as a potential alternative source for synthesizing carbon supported catalyst.

Pectin extraction: Pectin is extracted from the carrot using dilute mineral acid (hydrochloric acid, nitric acid and sulphuric acid) and recovered by precipitation with ethanol. As these mineral acids are not environment friendly due to toxicity, organic acids like citric acids are used for extraction process (Pereira *et al*., 2016; Jafari *et al*., 2017). The cleaned carrot slices were crushed and pressed to obtain the juice and carrot pomace. Pomace is dried for 16 hours at 50°C and grind to make a powder to pass through a 40 mesh sieve. Dried pomace powder is stirred in citric acid (liquid solid ratio 23.3 v/w) to attain the desired pH (1.3) and mixture was extracted at temperature (90°C) for time (79 min). The filtrate was allowed to cool at room temperature and then added with ethanol 2:1 v/v and refrigerated. Centrifugation of mixture for 15 min makes precipitate which then dried at 40°C for 16 hours to produce carrot pomace pectin (Jafari *et al*., 2017). Jafari *et al*., (2017) reported that pectin yield (16.0%) was significantly affected by pH value, temperature of extraction and time. Comparison of carrot pectin with citrus, apple pomace, papaya peel revealed the similar properties in terms of *galacturonic* acid content, emulsifying and rheological properties

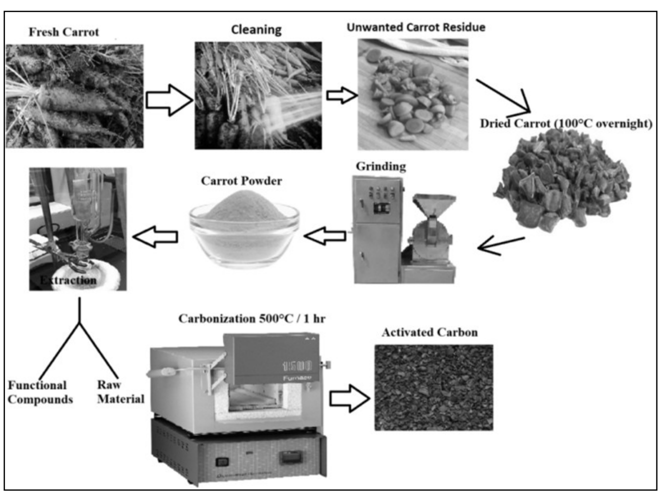

Fig. 6: Steps in production of activated carbon from carrot

By-product utilization: Carrot pomace, the by-product of carrot juice extraction process which yields up to 50% has been mainly disposed as feed or manure, is the rich source of carotenoids, dietary fibre which have beneficial impact on human health, such as reducing the risk of coronary heart disease, colon cancer, obesity, high blood pressure and stroke (Chau *et al*., 2004; Nocolle *et al*., 2003;), uronic acids and neutral sugars (Stoll *et al*., 2003). Dried carrot pomace contains β carotene in the range of 9.87-11.57 mg and ascorbic acid varies from 13.53-22.95 mg per 100g (Alam *et al*., 2016). It contains wide number of micronutrients such as Fe (30.5±0.14), Zn (29.4±0.16), K (18.6±0.10), Mn (10.8±0.12), Cu (4.0±0.07), Na (3.2±0.08), Ca (3.0±0.06), P (1.8±0.04) and Mg (1.1±0.05) (Tanska *et al*., 2007). Nawirska and Kwasniewska (2005) reported that dietary fibre of carrot constitutes cellulose (51.6%), hemi-cellulose (12.3%), lignin (32.1%) and pectin (3.88%). Efforts have been made worldwide to utilise carrot pomace in the production of cake, bread, high fibre biscuits and ready to eat extruded snacks and pastas (Alam *et al*., 2016; Kumari and Grewal, 2007). Kumar *et al*., (2010) have incorporated carrot pomace in extruded rice flour product and reported that expansion ratio of the carrot product was significantly influenced at the rice flour level of 11.75g/100g of carrot pomace. Kaisangsri *et al*., (2016) also reported that inclusion of carrot pomace in a corn starch at the level of 5g/100g resulted into to highest expanded product. Alam *et al*., (2016) included broken rice, defatted soybean flour, cauliflower trimmings in carrot pomace and reported that the optimum condition of 164°C die temperature, 313 rpm screw speed rice: defatted soy flour: carrot pomace flour: cauliflower trimmings powder (85:7.5:3.25:3.25) blend had 76.0% of desirability value. Efforts were also made to incorporate carrot pomace in rice flour, wheat flour, pulse flour and cheese powder to develop ready to eat snacks of higher fibre content (Alam *et al*., 2015a). Shelf life study of rice flour, chickpea flour, carrot pomace powder and cheese powder (75:11.25:11.25:2.5) based expanded products revealed that snacks were acceptable up to six months. Vacuum packaging in aluminium laminated samples were found to be best with highest overall acceptability (84.90%) (Alam *et al*., 2015b). Aimaretti *et al*. (2012) have successfully produced bioethanol from carrot waste using enzymatic hydrolysis process (Fig. 7).

Carrot leaves: Carrot leaves can be used as low cost source of nutrients to increase the nutritional value of the diet. Fully developed fresh carrot leaves after 100 days has significant amount of saturated fatty acid that has largest concentration of palmitic acid of 396 mg/100g, stearic acid 358 mg/100g whereas little significant amount of myristic, behenic and lignoceric acids. Proximate composition of the dehydrated carrot leaves had excellent quantity of total protein (21%), ash (15%) and total lipids (5%). In addition to the nutrients, it is rich in minerals such as Ca (0.05 mg/100g), Na (73.75 mg/100g), K (476.85 mg/100g), Mg (0.33 mg/100g) and Mn (0.11 mg/100g) (Leite *et al*., 2011). Dehydrated powder of the carrot leaves can be incorporated in production of soups, broths etc.

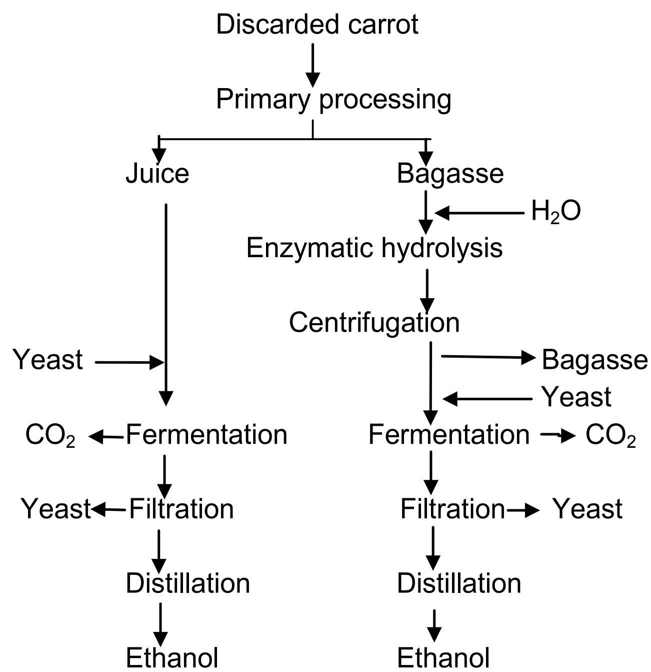

Fig. 7: Steps in the production of carrot based bioethanol

Future Scope in Carrot Processing

The manufacturers concerned with product development are required to use the by-products at the plant itself or transport it to other industries (bakery or extruded products industry) where by-products of carrot can be utilized into production of cake, bread, high fibre biscuits and ready to eat extruded snacks and pastas, thereby complete utilization of all products and by-products.

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