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Novel method for valorization of by-products from carrot discards

Adriana Clementz[a,*], Pablo A. Torresi[a,b], José S. Molli[b], Daniel Cardell[b], Enrique Mammarella[b], Juan C. Yori[a,b]

[a] Instituto de Investigaciones en Catálisis y Petroquímica (INCAPE) FIQ-UNL-CONICET, Parque Tecnológico Litoral Centro, 3000, Santa Fe, Argentina
[b] Facultad de Ingeniería Química. Universidad nacional del Litoral, 3000, Santa Fe, Argentina

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ABSTRACT

Large quantities of carrots are annually discarded in different parts of the world because they do not meet market standards. Besides the economic loss to the producers, the discard poses an environmental problem. In order to decrease the environmental impact produced by carrot discards and increase the sustainability of this important primary crop, an integral process of extraction of valuable by-products from discarded carrots (ethanol, carotene and a fiber rich fraction), is proposed in this work. Three processes that differ in the quality of the product obtained, the yields achieved, the equipment used and hence the costs involved are suggested. The selected procedure allows extracting 97% of fermentable sugars, which were used as feedstock for a fermentation reactor. The concentration of bioethanol obtained after fermentation process was 28.8 g L^{-1}. Bioethanol was subsequently used as a solvent for extraction of carotenes, thus reducing process costs. The extraction yield for carotenes was 94.2%. The composition of dietary fiber in the discards was also assessed. The soluble fiber (SDF)/insoluble fiber (IDF) ratio was 1:2.77, indicating that the fiber could be suitable for food supplementation.

1. Introduction

Carrot world production has increased significantly during the last 30 years (Rubatzky & Yamaguchi, 2012). In Argentina the annual production of this crop reaches 300,000 tons, being concentrated in four provinces: Buenos Aires, Santa Fe, Mendoza and Santiago del Estero (Gaviola, 2013). In Santa Fe, the cultivated area of carrots (*Daucus carota)* is about 1500 ha and the average yield is nearly 80 t ha^{-1} (Aimaretti & Ybalo, 2012). After the harvest, the carrots that not meeting the quality standards and the requirements of size and shape imposed by the consumer market, are discarded. As a consequence packing companies generate a big amount of discard, approximately 30% of the harvest, which is used as cattle food (Aimaretti, Ybalo, Rojas, Plou, & Yori, 2013). The estimated discard volume is 80–100 t d^{-1} during the harvest time (June to December) (Aimaretti & Ybalo, 2012). Besides the economic loss, the discard also becomes an environmental problem because only 15–20% is consumed by the animals, the rest being rotted and generating bad odors, proliferation of insects and decomposition products. This problem is repeated in other production areas of the country and similar producing countries of America and Europe. In order to provide sustainability to the production of such an important primary product, it seems essential to process the significant volume of carrot discards. The generation of valuable by-products from the discards would allow a different positioning of this traditional crop.

Carrots contain several compounds that can be used in the food and chemical industries: sugars (9–11%), carotenoids (0.01–0.02%), pectins (1–1.5%) and other fibers (2–5%) (Sharma, Karki, Thakur, & Attri, 2012). Main sugars present are sucrose, fructose and glucose, all of them capable of being fermented by yeasts to produce bioethanol (Aimaretti & Ybalo, 2012). Bioethanol has many applications in different industries (fuels, beverages, pharmacopeia, scents). Unlike raw material with high sugar concentration, such as sugarcane or molasses, the ethanol production from carrot sugars has not attracted interest in ethanol business circles due to the relatively low concentration of sugar in the crop, leading to low profit margins for the produced alcohol (Mussatto et al., 2010). In this sense it seems obvious that the processing of carrot discards should include the integral recovery of sugars, carotenoids and fibers.

Carotenoids are important nutrients that have diverse functions and effects in food. In carrots, the attractive orange color is their most apparent contribution to quality. Carotenoids have also biological functions. Their intake has multiple benefits on the human health such as the enhancement of the immune system and a reduction of the risk of

* Corresponding author. Instituto de Investigaciones en Catálisis y Petroquímica (INCAPE) FIQ-UNL-CONICET, Parque Tecnológico Litoral Centro, 3000, Santa Fe, Argentina.
E-mail address: clementz@iprobyq-conicet.gob.ar (A. Clementz).

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occurrence of degenerative diseases, cancer, cardiovascular disease, age related muscular degeneration and cataract formation (Burkhardt & Volker, 2007). The main pigments of carrot are α- and β-carotene. According to Fikselová, Šilhár, Marecek, and Francáková (2008), the carotene content of carrots ranges from 60 to 120 mg 100 g^{-1}, which can be extracted efficiently and then supplied to the market (food industry, pharmacopeia, etc.) as a valuable ingredient.

Other by-products that could be recovered from carrots are the dietary fibers: undigestible complex carbohydrates found in the structure of plants that could be used as dietary supplements or additives for the preparation of functional foods (Anderson, Smith, & Guftanson, 1994). Fibers are classified into insoluble and soluble depending on their solubility in water. Pectins (soluble fiber) are a class of complex polysaccharides found in the cell wall of higher plants, where they function as a hydrating agent and cementing material for the cellulosic network (Muralikrishna & Taranathan, 1994). These compounds have the ability to form gels in the presence of Ca^{2+} ions or a solute at low pH (Thakur, Singh, & Handa, 1997). Due to this property, pectins are used in jams, jellies, frozen foods, and in low-calorie foods as fat or sugar replacers.

The selective extraction of some components from a solid matrix employing appropriate solvents is a known operation. In the case of sugars, water is certainly the most effective solvent, but extraction must be carried out at temperatures that affect the carotenes. Carotenoids are insoluble in water and should be extracted using a suitable organic solvent. The main disadvantage of this option is the high cost of solvents and their potential toxicity if the product will be used for human consumption (Schoefs, 2004). Therefore, the selection of the solvent is an important factor in the development of a technically and economically feasible process. In this work, the selected solvent was ethanol due to the following advantages: i) it is a by-product of the global process and thus reduces the costs of extraction; ii) it is a relatively efficient solvent for the extraction of carotenes; iii) it is a food compatible solvent and hence the toxicity problems associated to the incomplete removal of the solvent, disappear.

The objective of the present work was to develop an efficient process for producing the maximum possible amount of valuable by-products from carrot discards, while reducing to a minimum the amount of equipment and materials used. No information about the simultaneous processing of these by-products was found in industrial patents, scientific publications or food technology textbooks. The paper analyzes the advantages and disadvantages of three different extraction processes as well as the properties of the by-products obtained.

2. Materials and methods

2.1. Raw material

Discarded carrots (*Daucus carota*), were collected from a packing shed in the Garay department area (31° 25′ S, 60° 20′ W), Santa Fe Argentina. As for handling and storage, the method described by Aimaretti and Ybalo (2012) was used, which consists of extracting the areas of carrots attacked by microorganisms and then storing the discards at 4 °C until their use.

2.2. Microorganism

Saccharomyces cerevisiae was provided by a local supplier (Calsa, Argentina) in the form of pressed yeast and it was reactivated directly in the carrot juice. Whole yeast cells were kept in a sterile container, without addition of nutrients, at 4 °C and saturation humidity, during six days. Inoculum for fermentation assays were incubated in a shaker at 100 rpm, 30 °C, for 24 h. The inoculum was adjusted to a value of 10^8 cell mL^{-1} (Aimaretti & Ybalo, 2012). Free cells were employed.

2.3. Analytical methods

2.3.1. Chemical composition of carrot

Contents of moisture, ash, fats and total dietary fiber (soluble and insoluble) were determined employing AOAC standard methods 934.01, 942.05, 922.06, 991.43, respectively (AOAC, 2000). The nitrogen content was determined by the Kjeldahl method 2001.11(AOAC, 2000). Protein content was estimated as the nitrogen content multiplied by 6.25.

The mineral composition (Ca, P and Fe mass content) of carrots was determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES, in a Perkin Elmer, Optima 2100 DV) after digestion in an acid solution of 1:5 (v v^{-1}) nitric:perchloric acid.

2.3.2. Water-holding capacity (WHC), oil-holding capacity (OHC) of carrot fibers

Water-holding capacity (WHC) and Oil-holding capacity (OHC) of carrot fibers were determined following the methodology described by Robertson et al. (2000).

2.3.3. Sugar concentration

The concentration of total sugar was measured by the 3.5- dinitrosalicylic acid (DNS) method after acid hydrolysis (1.2 M HCl at 65 °C for 15 min), neutralization with 1 M NaOH, and filtration (Yu, Zhang, & Tan, 2004).

2.3.4. Carotenoids quantification

The quantification of carotenoids was carried out by high-pressure liquid chromatography (HPLC) using an Agilent 1100 Series equipment. The column used was C18 (Supelco Discovery) (15 cm × 4.6 mm y 5 μm). The mobile phase was acetonitrile:methanol:ethyl acetate (73:20:7). The peaks were monitored by measuring the absorbance at the 450 nm wavelength. Carotenoids were identified on the basis of retention times and relative elution order as compared to standards: α and β carotenes and literature values (Rodriguez-Amaya, 2001).

2.3.5. Ethanol concentration

Ethanol concentration was measured by gas chromatography in a Shimadzu GC 2014 apparatus equipped with a ZB-wax capillary column. Isopropanol was used as internal standard. The column temperature was 40 °C (isothermal), the injector and the detector temperatures were equal to 220 °C.

2.4. Proposed processes for the revalorization of the carrots

For the extraction of carrot by-products, three processes were proposed. A summary of these procedures is given in Fig. 1.

2.4.1. Process 1 (P1)

Discarded carrots previously washed and conditioned in the packing shed, were fed to a blade grinder, in order to reduce their size. The blades were adjusted so as to obtain thin slices (0.01 mm) which were called “flakes”. A similar procedure is employed in the extraction of sugar beet. Carrots were sliced into thin chips in order to increase the surface area thus making extraction easier (Van der Poel, Schiweck, & Schwartz, 1998). The sugars stored in the vacuoles of the carrots were extracted using hot water, a technique of high efficiency and low cost. The extraction was performed in a jacketed batch reactor according to the following procedure: about 1000 g of carrot flakes were placed in the reactor with 1500 g of water. After sealing the reactor, it was heated through the jacket to 60 °C, while stirring gently at 100 rpm for 15 min (Chen & Huang, 1998). When the stirring was stopped, the aqueous phase (must) and bagasse (solid) were separated by filtration. The bagasse was placed in a Soxhlet-type extractor. Ethyl alcohol (95.5%) was used for extraction, with a solid-liquid ratio of 1:1. It was recirculated through the bagasse at 60 °C for 15 min. In order to remove most

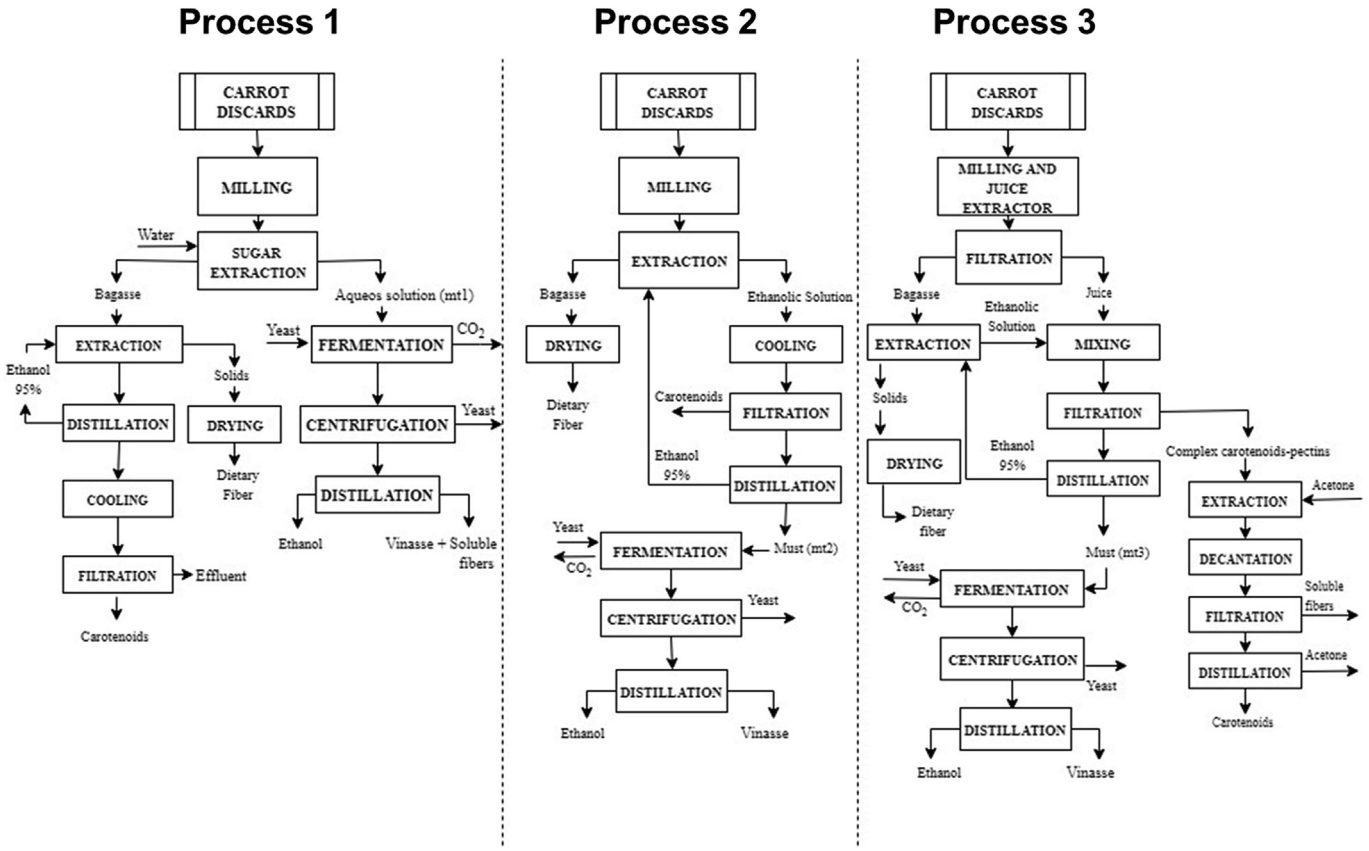

Fig. 1. Schemes of the three proposed processes of extraction.

carotenoids, four stages of extraction were used. Each stage was repeated with the same conditions and fresh solvent. At the end of the process, the solid was separated by filtration, dried in a stove and stored as carrot dietary fibers. The alcohol was recovered by atmospheric distillation for further use. The residue containing carotenoids and water, was cooled down to 8 °C in order to precipitate the carotenoids that were then separated by filtration. The final effluent of this technique is water.

The must (mt1: see Fig. 1), containing sugars, soluble fibers and the remnant carotenoids, was introduced into the fermenter where the sugars were converted into ethyl alcohol (bioethanol) by the action of the biocatalyst (yeast). The fermentations conditions are exposed in section 2.5.

2.4.2. Process 2 (P2)

A sample of 1000 g of carrot flakes 0.1 mm thick was placed in the Soxhlet extractor. The reservoir was charged with ethyl alcohol (95.5%) and heated to 60 °C. The solid-liquid ratio was 1:1. The solvent was kept at constant temperature and with constant stirring for 15 min. Four consecutive extraction stages were carried out using fresh solvent in each of them. At the end of the extraction process, the solid was removed by filtration and dried in a stove as carrot dietary fibers. The alcoholic phase containing sugar, water and carotenoids was cooled to a temperature of 8 °C in order to precipitate the pigments (carotenoids) which were separated by filtration. The alcohol was recovered by atmospheric distillation and the must (mt2) was fermented according with section 2.5.

2.4.3. Process 3 (P3)

Samples of 1000 g of whole carrots were processed in a juice extractor. After this process, two products were obtained: bagasse and must, 450 g and 550 g respectively; which were separated by filtration. The bagasse was placed in a Soxhlet equipment for extracting carotenes and using the same conditions previously described (See 2.4.2). The alcoholic phase obtained after extraction was mixed with the carrot juice previously produced. After contact, the precipitation of a solid carotenoid-fiber complex occurs that was then separated by filtration. The alcohol was recovered by atmospheric distillation and the must (mt3) was fermented following the conditions described in section 2.5.

The carotenoid-fiber complex was treated with 50 cm^3 of acetone at room temperature in a stirred reactor for 15 min in order to produce the precipitation of water soluble fibers that were separated by filtration (Perussello, Zhang, Marzochella & Tiwari, 2017). Finally acetone was eliminating by vacuum distillation leaving the carotenoids as the final residue.

2.5. Fermentation conditions

Fermentation was carried out in the absence of oxygen (anaerobiosis) at 30 °C, pH 4.5 and its progress was monitored by checking the formation of CO_2. At the end of the process, the fermented must was distilled in two packed distillation columns at atmospheric pressure obtaining ethyl alcohol (95.5%) and vinasse.

The following fermentation parameters were calculated to compare the responses of different assays: (i) $Y_{p/s}$ [g g^{-1}] ethanol yield per substrate, is the ratio of total ethanol produced to the amount of consumed sugar; (ii) productivity [g L^{-1} h^{-1}], is the ratio of the amount of alcohol produced to the total fermentation time (Colin & Bjorn, 2002). In all instances, the total fermentation time was 4 h.

2.6. Statistical analysis

To examine the repeatability of the experiment, three experimental runs of each batch test were carried out and measurements were performed in duplicates. The data were analyzed using the one-way ANOVA procedure of R Statistical software. Differences between means

Table 1
Chemical composition of the carrot discard. Results were expressed as % dry matter.

Nutrient	*Percentage (%)*
Carbohydrates	67.867 ± 0.020
Fats	0.714 ± 0.010
Protein	6.428 ± 0.020
Ash	6.144 ± 0.003
Carotenes	0.100 ± 0.001
Calcium	0.571 ± 0.001
Phosphorous	0.214 ± 0.001
Iron	0.071 ± 0.001
Fiber	22.785 ± 0.010
• Insoluble fiber	16.715 ± 0.50
• Soluble fiber	6.033 ± 1.200

Values are means ± standard deviations (n = 10).

were detected using the Tukey Test. Data were considered significantly different when $P < 0.05$.

3. Results and discussion

3.1. Carrot discards composition

The chemical composition of carrot discards in the packing shed is detailed in Table 1.

In the worldwide market about 120 different varieties of carrot are present, which logically have differences in their chemical composition (Bejo Carrot Magazine, 2017). Similarly as packaged carrots, discarded carrots have optimal maturity and freshness level. This makes them suitable for treatments for producing added-value products (Sánchez & Cardona, 2008). In accordance with Table 1, carrot discards have also the nutritional characteristics (P, Ca, Fe) necessary for the growth of the microorganisms employed in the production of ethanol production.

3.2. Optimization of carotenoids extraction process

Carotenoids are liposoluble compounds that are usually extracted from plants with organic solvents such as chloroform, hexane, acetone, diethyl ether or pyridine (Meléndez-Martinez, Vicario, & Heredia, 2007). The three procedures proposed in this investigation employ ethanol as the solvent. Although this solvent is not the most effective for recovering carotenes and nowadays new technologies are applied (Kumari, Tiwari, Hossain, Brunton, & Rai, 2018), it was selected because it is a by-product of the process and thus helps in reducing operation costs.

Fikselová et al. (2008) found that the maximum amount of carotenoids extracted from carrots employing ethanol as solvent at 60 °C, was 51% after 2 h of extraction. After this time, the pigment concentration in the solvent was maintained constant in spite of increasing the time of extraction. This fact could point to a possible saturation of the solvent. In order to determine the optimal extraction parameters: solvent quantity, temperature and time of the process, several extractions using fresh solvent and a mass ratio carrot:ethanol of 1:1 were made. Fig. 2a shows that the amount of carotenoids removed increases at higher numbers of extractions. In the first stage 19.5% of pigments were recovered, equivalent to 0.002 g 100 g^{-1} of total carotenoids present in the sample (Table 1). At the end of the fourth extraction the yield increased to 100%. It is clear that four extractions are needed to reach the maximum yield. As seen in Fig. 2 b that 60 °C is enough to obtain high extraction yields ($P > 0.05$) Fikselová et al. (2008) reported that the best yields were obtained at 60 °C due to a good release of carotenes from the disturbed texture of the carrot. At this temperature the yield of carotenes extraction was found to be high after 15 min of the process ($P > 0.05$, Fig. 2c). In accordance with the results, four stage of extraction at 60 °C and 15 min is necessary in order to obtain the best yields of carotenes.

3.3. Selection of extraction process

The extraction process was selected mainly on the basis of the yield of each by-product. This yield is the weight percentage of by-product with respect to its initial amount in the raw material (see Table 1). Other factors to be analyzed are the amount of solvent used, the number of stages and the necessary equipment involved in each process. These factors dictate the cost of installation and operation of the process. The volume of effluent produced and its possibility of reuse were also considered.

Yields and values of the mass ratio carrot:water employed in each technique are shown in Table 2. According to these results P3 is the technique that produced the highest amount of sugar. The lowest yield is generated when using P1, even though this process had a specific sugar extraction stage. This is because much sugar remain in the bagasse when using water as a solvent.

The highest carotenoid yield was obtained with the process P3. The bad results with P1 could be related to a degradation of the carotenoids at the high temperature used (100 °C) in the distillation step. As seen in Fig. 1 the carrot pigments were recovered after ethanol distillation and hence they could have been thermally degraded. Carotenoids are highly unsaturated compounds that are degraded by oxidative processes generated by heat or light (Meléndez-Martinez, Vicario, & Heredia, 2004). Chen and Huang (1998) reported that the degradation of all-trans- beta-carotene became significant after heating at 50 °C for 25 min or at 100 °C during 10 min. Similar results were reported by Calvo, Dado & Santa Maria (2007) for extractions of lycopene with ethanol. P1 had also another drawback, carotenoids being likely lost during the extraction with water. Although this type of pigments has a higher solubility in non-polar solvents, a small fraction of them could have been lost during the treatment (Fikselová et al., 2008). Indeed carotenoids are visibly present in must obtained at the end of the extraction sugars extraction that has an orange color. In section 3.5 the incidence of carotenoids in the fermentation process was analyzed. In procedure P2 the cooling stage carried out after the extraction process (Fig. 1) produced the precipitation of carotenoids because of a reduction of solubility (Três et al., 2007). Carrot pigments that were removed by filtration had a yield as reported in Table 2. After ethanol distillation probably the (mt2) still contained carotenoids capable of being extracted by filtration after cooling, but these compounds were degraded at the high temperature of the bottom of the distillation tower. The yield of carotenoids of technique P3 was the highest. Pigments were not thermally degraded. The production of juice in the first stage (Fig. 1) increased the availability of carotenoids due to the disruption of the cell wall by the mechanical process. When ethanol and carrot juice were mixed, the temperature of the final solution decreased affecting the solubility of carotenes. The soluble fibers present in the juice, insoluble in ethanol adsorbed the carotenoids, prompting the precipitation of the carotenoid-fiber complexes. This complex was removed by filtration before alcohol distillation (Fig. 1). In this way the thermal degradation of carotenoids was prevented.

The use of water as solvent for extracting sugars in P1 produced the leaching of soluble fibers into the fermentation must. The recovery of fibers from aqueous solution would demand additional equipment increasing the process costs. After the fermentation the recovered ethanol was placed in the distillation tower. The high temperature reached in this process produced the degradation of the soluble fibers which were retained in the vinasse (Gow-Chin & Hsin-Tang, 1998). In process P2, the soluble fibers were retained in the bagasse, due to the low solubility of these compounds in ethanol. The recovery of its from the bagasse would demand additional stages of separation, with the associated increase in process costs. Moreover, the obtaining of these compounds only occurs in P3 due to the formation of the carotenoid-fiber complex. This complex was removed before distillation thus avoiding the

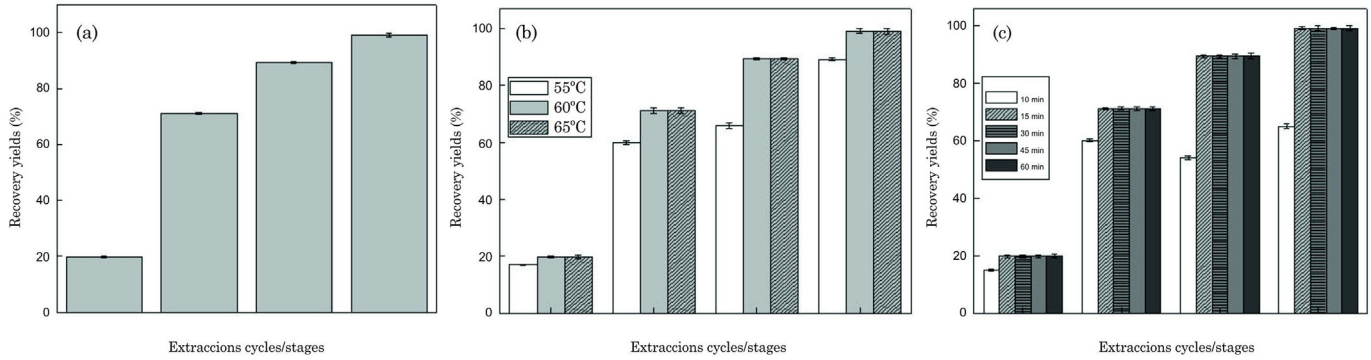

Fig. 2. Carotenoid yields as a function of (a) the number of consecutive extraction stages, (b) temperature and (c) time of the process.

Table 2
Yields and values of the extraction, carrot:water mass ratio.

Process	*Sugar %*	*Carotenoids %*	*Soluble fibers%*	*Carrot:water mass ratio*
P1	82	82.5	–	1:5
P2	90	64.7	–	–
P3	97	94.2	50	–

Values are means ± standard deviations (n = 3).

degradation of the fibers. The soluble fiber, pectins probably, obtained correspond to those recovered in the carrot juice.

The operation costs are another important parameter to evaluate. Process P1 has an additional stage, extraction of sugars with water. Even though this step has its advantage, it involves energy and extra equipment. According with the amount of solvent used, the results obtained in section 3.2 indicate that the optimal bagasse:ethanol ratio was 1:4. In procedure P3 carrots were processed to extract their juice with a continuous extractor. The yield of this stage was 0.54 kg kg^{-1} of juice and 0.46 kg kg^{-1} of bagasse. It can be seen that extraction in this technique used half the mass of P1 or P2, thus reducing the consumption of solvent.

The possibilities of reuse of some effluents should be considered. The amount of water left after sugar extraction in P1 is an effluent of this process. The effluent produced in P2 and P3 is the water that contains the carrot due to both methodologies do not incorporate water in the process.

The vinasse produced at the end of the ethanol distillation in P1, P2 and P3 can be used in dilution with water (1:5) for animal feed, or in higher dilution (1:10) as irrigation water of carrot crops (Aimaretti, Clementz, Codevilla, Rojas, & Yori, 2013). In this sense P2 and P3 are processes that do not produce harmful effluents but produce streams of beneficial use.

Finally it can be said that P3 gives the highest quality and yields of carrot by-products. The production of juice in P3 increased the recovery of each by-product. The cost of this process is low because of the low amount of equipment needed. Due to these advantages P3 process was selected.

3.3. Dietary fiber

Dietary fiber (DF) is the edible part of plants that is resistant to hydrolysis by digestive enzymes in humans. It contains membrane components, as well as endocellular polysaccharides (Nawirska & Kwaśniewska, 2005). The proximate composition of carrot fiber is described in Table 3. Fiber of carrot discards can be milled and used directly as food ingredient because it contains low amounts of fat, protein, and ash (Elleuch et al., 2011).

DF is subdivided into insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) according to their solubility in water. IDF consist mainly of cell wall components such as cellulose, hemi-cellulose and

Table 3
Composition of carrot fiber obtained from Process 3. Results were expressed as % dry mater.

Component	*Content (%)*
Moisture	11.18 ± 0.13
Fats	0.17 ± 0.01
Protein	7.97 ± 0.42
Ash	6.99 ± 0.28
Total dietary fiber	74.00 ± 0.22
• IDF	54.30 ± 0.50
• SDF	19.60 ± 1.20

Values are means ± standard deviations (n = 3).

lignin while SDF is made of non-cellulosic polysaccharides such as pectin, gums and mucilage (Yoon, Cha, Shin, & Kim, 2005). The total dietary fiber content in carrot discards was 74 ± 0.22% dry sample, where 54.3 ± 0.5% corresponds to IDF, and the remaining 19.6 ± 1.2% to SDF. These results were higher than those reported by Chantaro, Devahastin, and Chiewchan (2008) for dehydrated carrot. The loss of components such as carotenoids, minerals, vitamins and sugars from the plant cells into the ethanol that occur during extraction, leading to a relative increase in the contents of dietary fiber.

The SDF/IDF ratio is important for dietary and functional properties, structural and sensorial properties. It is generally accepted that those fiber sources suitable for use as food ingredient should have an SDF/IDF ratio close to 1:2 (Lucas-Gonzales, Viuda-Martos, Perez-Alvarez & Fernandez-Lopez, 2017; Tales, Arboleya, Castro-Giraldes & Fito, 2017). The SDF/IDF ratio in this investigation was 1:2.77. In this respect, carrot fiber provides a very suitable tissue for food supplementation.

Water-holding capacity (WHC) is defined as the quantity of water that is bound to the fibers without the application of an external force (except for gravity and atmospheric pressure) (Thebaudin & Lefebvre, 1997). The WHC value obtained from carrot discard fiber was 18 g g^{-1}. This value is higher than the agricultural by-product from other fibers, e.g., 10 g water g from sugar beet $fiber^{-1}$, 4.5 g water g from apple $fiber^{-1}$, 3.1 g water g from wheat $fiber^{-1}$ (Thebaudin & Lefebvre, 1997). This high value of WHC may be due to the presence of high-soluble fiber substances (Lv, Liu, Zhang, & Wang, 2017). On the basis of this value carrot dietary fiber could be used as an ingredient in food products, e.g. for preventing synaeresis and modifying the viscosity and texture of some formulated foods (Grigelmo-Miguel & Martina-Belloso, 1999).

Oil holding capacity (OHC) is the amount of oil retained by the fibers after mixing, incubation with oil and centrifugation (Elleuch et al., 2011). The OHC value of carrot discards was similar to dehydrated carrot, 5 g fat g of $fiber^{-1}$ and of 5.5 g fat g of $fiber^{-1}$, respectively (Eim, Simal, Rossello & Fenemia 2008). The OHC value found is however higher than those of other by-products such as apple (1.3 g g of

Table 4
Fermentation tests results obtained with two different substrates.

Must	*Sugar (g L^{-1})*	*Ethanol concentration (g L^{-1})*	*Yp/s (g g^{-1})*
Carrot juice	80.00 ± 0.20	22.70 ± 1.20	4.54
mt3	144.00 ± 0.25	28.80 ± 0.90	4.43

Values are means ± standard deviations (n = 3).

fiber^{-1}) or sugar cane bagasse (3.26 g g of fiber^{-1}) (Sangnark & Noomhorm, 2003). This OHC value suggests the possibility of using the fibers for the stabilization of high fat food products and emulsions (Elleuch et al., 2011).

3.4. Fermentation

The use of carrot juice without any treatment as substrate of alcoholic fermentation was reported by our investigation group in several papers (Aimaretti & Ybalo, 2012; Clementz, Aimaretti, Manuale, Codevilla & Yori, 2015). The juice provide the necessary ions and the appropriate C:N balance for ethanol production. It was not necessary to enrich the juice with the addition of micronutrients such as P, K or N because these compounds were already contained in the carrot.

In this section the must obtained in P3 (mt3) after filtration of the complex carotenoids- fibers and ethanol distillation (Fig. 1), was fermented in order to analyze the effect caused by the absence of carotenes and fibers in the alcoholic fermentation. Table 4 shows the Yp/s values obtained when two substrates were employed: i) carrot juice from the extractor, and ii) mt3. The results indicated that no significant differences in Y p/s values ($P > 0.05$) was found when using different substrates, thus, mt3 has the necessary nutrients for the growth of yeast and the alcohol production in despite of carotenes and fibers extraction.

The higher concentration of ethanol produced using mt3 (Table 4) is due to the enhanced extraction of sugars in P3. Aimareti et al. (2012) reported that the ethanol production is proportional to the sugar concentration of substrate. According to the results obtained, mt3 would be a suitable substrate for alcoholic fermentation.

4. Conclusions

Three processes of simultaneous extraction of carrot by-products were proposed. The select process (P3) allowed extracting 97% of fermentable sugars which were then used as substrate for bioethanol production. This solvent was subsequently used in the extraction of carotenes and fibers, thus reducing process costs.

Process 3 provided the highest yields of theses by-products: 5200 L of ethanol, 3200 kg of fiber rich fraction (soluble and insoluble) and 13 kg of carotenoids from 100 ton of carrot discards. In Argentina, the market price of these products are: 1 USD per lt of ethanol, 8–10 USD per kg of fiber, 500 USD per kg of carotenes. Process 3 revalue a residue that is generated in large quantities in the world, allowed obtaining by-products with high value added without generating new discards.

Conflicts of interest

The authors declare no conflict of interest.

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