Application and the Techno–economical Aspects of Integrated Microwave Drying Systems for Development of Dehydrated Food Products

Nora SALINA MD SALIM1,2, Jiby KUDAKASSERIL KURIAN1, Yvan GARIEPY1, Vijaya RAGHAVAN1,†

1Department of Bioresource Engineering, Faculty of Agricultural and Environmental Sciences, McGill University, Macdonald Campus, 21,111 Lakeshore, Ste–Anne–de–Bellevue, Quebec, Canada H9X 3V9.
2School of Fundamental Science, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

The demand to increase food production to feed the growing number of the world population is becoming a primary concern for everyone. At the same time, one-third of the food produced is lost or wasted globally. The food wastes and the by-products of the food production and processing operations still have nutritional ingredients in them suitable for human consumption. To encounter this issue, drying methods can be carried out to add value to food waste, prolong the product’s shelf life and thus provide more food products. Integrated microwave drying systems have the potential to produce dehydrated products from the food waste. In this paper, integrated osmotic dehydration with microwave-assisted hot air drying method is described for the development of dehydrated broccoli stalk product. The techno–economical aspects in terms of raw material availability, process design, energy input, capital inputs, operation costs and environmental benefits are also discussed. This integrated microwave drying concept will be of use to process other biological materials that have the potential at the marketplace.

Keywords: Food security, food waste, integrated drying, microwave–assisted, techno–economic aspects.

1. Introduction

The world population is projected to rise to 11.2 billion by the end of this century [i]. To feed this growing population, the current global food production also needs to be increased. However, an estimated one-third of the food produced in the world now ends up as waste in landfill sites [ii]. Decomposition of this waste leads to the emission of greenhouse gases and thus contributes to climate change. In this scenario, wastage of food must be recognized as a global problem that has a huge impact on the economy, environment, and society. Therefore, concerted efforts to prevent wastage along the entire food supply chain are required to provide more food for human consumption and reducing the greenhouse gas emissions [iii].

Food supply chain is divided into five major process steps such as production, post–harvest handling and storage, processing, distribution, and consumption.

According to the FAO (2013) [iv], 54% of food wastage occurred at production and post–harvest handling and storage stages. Processing, distribution and consumption stages contribute to the remaining 46% of the total wastage. Poor harvesting techniques and improper handling of the crop produce during harvesting, especially in developing countries, also contributed to the food wastage [1–3]. In terms of food commodities, 44% of the total wasted food are fruits and vegetables [1]. Commonly, the production and processing of fruits and vegetables also generate crop remains and by–products that are usually discarded. However, they still contain sufficient nutritional ingredients that can be used for producing value added products for human consumption. After harvesting, the crop produce and residues continue to be physiologically active and start to deteriorate over time. They continue to lose water and it affects their appearance, texture, flavour and nutritive value. Hence, post–harvest technologies become an important key to extending the shelf life of crop produce, adding value to the waste resources and provide more food for human consumption.

Drying is an important processing method for water
removal that reduces the water activity and extends the shelf life of food products. Drying operation facilitates the preservation and handling of foods and reduces the transportation and storage costs through the reduction in bulk density of the food material [4]. However, the challenges associated with the drying process, especially for thermal sensitive products, include reducing the moisture to a certain level where the products are shelf-stable and produce good quality products in terms of physical properties, nutrient contents, and sensory values. There are various improved drying technologies available for food processing at the current juncture, and hybrid drying technologies that combine two or more of the drying methods are one of the most promising options to meet the demands for increased food availability.

2. Integrated microwave drying system with osmotic dehydration as pre-treatment

Conventional heating techniques work remarkably at removing moisture from the surface of materials and the heat transfer inside the material decreases with an increase in distance from the surface. In recent years, electro-heating using microwave energy which has become one of the most efficient drying methods as the heat is volumetrically distributed within the food material. In addition to stand-alone microwave drying methods, it also can be combined with conventional drying methods such as convection and conduction to gain even better improvement to reduce the drying time and enhance the product quality [4]. A considerable amount of research studies has been published on microwave hybrid drying systems for various food materials [5-8]. In general, microwave-assisted drying provides a great synergy that can meet the four major requirements in the drying of foods: (1) Speed of operation; (2) Energy efficiency; (3) Cost of operation; and (4) Quality of the dried products [9].

Likewise, the osmotic dehydration method has received an increased attention as a potential pre-treatment for the preservation of food material. The Fig. 1 presents an overview of the 1227 articles published between 2010 and 2015 on osmotic dehydration.

Osmotic dehydration is the partial removal of water by immersing food material in a hypertonic solution. During immersion, the food material is exposed to a gradient of chemical potential between the hypertonic solution and the inside of food that results in an outflow of water from the food material and inflow of solute from the hypertonic solution to the food. The advantages of this dehydration technique as a pre-treatment prior to drying process are [10-12]: (1) Mass of fresh sample can be reduced by more than 50%; (2) Energy savings from the moderate temperature used, usually from 30 to 40℃ and water is removed without a phase change; (3) Shorten the drying time for finish drying; and (4) Improve product quality attributes such as color, texture, aroma and nutritional value.

Application of osmotic dehydration as a pre-treatment prior to microwave-assisted drying has been extensively studied in producing high quality dried products [13-15]. Torringa et al. (2001) [16] investigated the combined osmotic dehydration with microwave-hot air drying on mushroom and found that this hybrid drying method lowered the drying time and shrinkage of the dried product. Similar responses were reported by Changrue and Orsat (2009) [17] on carrots. In an earlier investigation on drying of broccoli stalk slices in our laboratory, it was found that the constant drying rate period is no longer present when the osmotically dehydrated samples were dried under microwave-assisted hot air drying. While, in term of product quality, the dried broccoli slices produced using the integrated osmotic dehydration with microwave-assisted hot air drying method was found to be better than the dried broccoli slices produced using either of microwave-assisted hot air or hot air drying methods [18]. Thus, it is imperative to evaluate the technical and economic aspects of this hybrid drying method as discussed in the next section.

Fig. 1 An overview of articles on osmotic dehydration from 2010 to 2015 [v].

© 2016 Japan Society for Food Engineering
3. Techno-economic aspects of the combined osmotic dehydration and microwave-assisted hot air drying of broccoli stalks

The following sections present a case study on how to add value to broccoli stalk slices, which is a harvest residue, as a dried product. Factors like raw material availability, process design, energy input, capital inputs, operation costs and environmental benefits that determine the sustainability of producing edible chips from broccoli stalks are discussed.

3.1 Raw material availability

Broccoli is a cool season cultivated crop, with the optimum growing temperature range between 15 to 22°C [19]. In Canada, the harvest season for broccoli begins in June and ends in October [vi]. The total production of broccoli in Canada in the year of 2015 was 41,456 tonnes, and this number has been steadily increasing since 2012 [20]. About 47.6% of this production is from the province of Quebec. Commercially, broccoli is marketed for its florets, while leaving a considerable amount of harvested remains in the supply chain. The composition of harvested remains is illustrated in Fig. 2. Thus, the estimated availability of broccoli stalks for processing, at an average farm size of 280 acres, in Quebec, Canada [21] is about 2.23 tonnes per day. This quantity of broccoli stalks is assumed as processed in two batches of 8 hours each operation per day of the drying facility.

3.2 Process design

The processing steps to produce osmo-dried broccoli stalk slices is illustrated in Fig. 3. The broccoli stalks are cleaned first and then the cleaned stalks are peeled and sliced. The broccoli stalk slices contain about 94% moisture content (w. b.). Sucrose solution at a concentration of 54 °Brix was prepared and heated up from 25°C to 30°C. Once the desired temperature is reached, the broccoli stalk slices are immersed in the solution for 2 hours. For finish drying, the osmotically dehydrated broccoli stalk slices are dried using microwave-assisted hot air at a drying temperature of 40°C, until it reached 10% moisture content (w. b.), after about 3.5 hours. The dried broccoli stalk slices are packed in printed polythene bags and cardboard boxes.

The data on process design and yields are based on the laboratory-scale work conducted at the Department of Bioresource Engineering, McGill University. For one tonne of fresh broccoli stalks, the production of dried broccoli stalk slices is estimated as 97.5 kg. The mass loss occurring at each stage of processing of a tonne broccoli stalk is given in Table 1.

During osmotic dehydration, water is transferred from broccoli stalk slices to the sucrose solution and sucrose is transferred into the broccoli stalk slices. The volume

![Diagram](image)

Fig. 2 The composition of broccoli harvest remains [22].

![Diagram](image)

Fig. 3 Flow diagram of processing of Osmo-dried broccoli stalks.
(in litre) of 54 °Brix sucrose solution required for osmotic dehydration per kg of broccoli stalks being processed is at a ratio of 20:1. For every tonne of broccoli stalks, about 11 tons of sucrose and 9 tons of water are required to be in the solution. After each batch of osmotic dehydration process, the sucrose solution can be recycled at least 10 times [24,25]. During osmotic dehydration, nutrients are also leaching into the sucrose solution and therefore, the recycled sucrose solution can be used elsewhere considering the nutrients in it [26-28].

The microwave-assisted hot air drying evaporates moisture from the osmotically dehydrated broccoli slices. This drying approach can minimize the retreating wet front, maintaining the evaporating surface and perhaps permitting entrainment-evaporation [11]. The rate of drying decreases with a decrease in moisture content. For every tonne of osmotically dehydrated broccoli slices, this stage evaporates about 0.67 tonne of water that can be condensed to use for the preparation of sucrose solution as well as to recover the heat energy in it.

### 3.3 Energy input

The important factor in the production of broccoli stalk chips, which greatly determines the product cost, is the total energy input. The energy required for heating sucrose solution as well as the energy to heat the broccoli slices could be estimated using Equation (1).

\[
Q = m \cdot C_p \cdot \Delta T \quad (1)
\]

Where, \(m\) is the mass (kg) of sugar solution and the broccoli slices; \(C_p\) is the specific heat (kJ/kg °C) of the sugar solution and the broccoli stalk slices, and \(\Delta T\) is the temperature (°C) difference from initial temperature to the processing temperature (30°C).

Considering the room temperature as 25°C and \(C_p\) value of the 54 °Brix sucrose solution as 2.95 kJ/kg °C and that of broccoli stalks as 3.85 kJ/kg °C, the minimum heat energy required for osmotic dehydration at 30°C is about 0.65 MJ/kg–water removal from broccoli stalk slices. In addition to this, energy should be given to compensate for the energy loss of the process. However, the energy required in the osmotic dehydration of broccoli slices will be minimal when the atmospheric temperature is higher than 30°C.

For the finish drying process, the energy to heat the osmotically broccoli stalk slices can be calculated using Equation (1), considering the \(C_p\) value of osmotically dried broccoli stalk slices as 3.56 kJ/kg °C. The energy required to evaporate water from the osmotically dehydrated broccoli slices during microwave-assisted hot air drying can be calculated using Equation (2).

\[
Q = m \cdot \lambda \quad (2)
\]

Where, \(m\) is the mass of water to be removed (kg) and \(\lambda\) is the latent heat of water evaporation, \(2.46 \times 10^3\) kJ/kg [29].

Therefore, the minimum energy input required for microwave-assisted hot drying of osmotically dehydrated broccoli stalk slices, to a final 10% moisture content level, is about 2.46 MJ/kg of evaporated water. Additional energy must be provided, considering the dryer efficiency and heat losses. The energy input for the drying of untreated broccoli stalks using a stand-alone microwave-assisted hot air dryer can also be calculated using the Equations (1) and (2). The total heat energy required to dry a tonne of broccoli stalks in the combined osmotic dehydration and microwave-assisted hot air drying process is about 68% less than that of the stand-alone microwave hot air drying of a tonne of broccoli stalks without any osmotic dehydration. This difference in the amount of energy required is due to the low moisture content of the osmotically dehydrated broccoli stalks that require less energy input for drying during the microwave-assisted hot air drying stage. The stand-alone microwave-assisted hot air dryer should remove 3.25 times more water from the untreated broccoli stalks than from the osmotically dehydrated broccoli stalks. Drying is the most energy intensive process in the pro-

| Process          | Mass loss description                        | Mass loss (kg) |
|------------------|----------------------------------------------|----------------|
| Washing          | Removal of impurities                        | 50             |
| Peeling          | Removal of peel                              | 95             |
| Slicing          | Removal of fine particles                    | 85.5           |
| Osmotic dehydration | Transfer of water into sugar solution      | 461.7          |
| Drying           | Water evaporation to reach 10% final moisture content | 205.2          |
| Packaging        | Loss during packaging                        | 5.1            |
duction of osmo-dried broccoli stalk slices. Additional energy, at the rate of about 5% of the total energy required for drying, will be used for operating the facilities for the handling of the materials and packaging of the dried product [30].

3.4 Capital inputs

Capital inputs refer to the cost of land, buildings, equipment and the working capital required to start the processing of broccoli stalks to chips [31]. Monetary inputs for land and buildings are required in establishing the processing facility. The area of land required is dependent on how much raw material is available at a given time and on the processing capacity of the facility. Space is required for the delivery and storage of raw materials, consumables, and products; processing, packaging, administration works, etc. The cost of the vegetable washer, peeler and slicer machines will vary depending on the machine specifications such as the input capacity and the infeed system type. Overall, the cost of automatic conveyer belt systems that will provide higher processing capacity will be higher than that of manually controlled conveyer systems.

For osmotic dehydration process, the direct heating method can be applied, since it is highly efficient due to direct absorption of heat by the sucrose solution from the heater. The cost of the microwave-assisted drying system includes that of a microwave generator, waveguide tube, applicator, control system and conveyer [32]. In this study, the costs of equipment are obtained from different manufacturers/suppliers and the estimated fixed capital cost is divided into the direct and indirect cost as shown in Table 2. The estimation percentage adapted from Masresha (2015) [30]. Additionally, the working capital is estimated at 15% of initial capital inputs incurred [30]. Thus, the total capital investment is found to be about CAD 311,717.

3.5 Operating costs

The operating costs can be divided into variable operating costs and fixed operating costs. Variable operating costs can be described as the cost of consumable items like sucrose, printed polythene bags, cardboard boxes, water, and electricity. Water is required for washing and cleaning of the raw material and the facility. While, electricity is required from sample preparation to packaging stages. Packaging materials like polyethylene bags are required for the storage and delivery of the processed broccoli stalk slices for consumption. The cost of consumable items is directly dependent on the quantity of broccoli stalk processed and the market conditions. The price of electricity and water are dependent on the local tariff.

Meanwhile, fixed operating costs will not vary much with the production rate as compared to variable costs. Fixed operating costs include, for example, the materials that are required for the maintenance and repairs of the processing machinery and the facility, wages for operating and maintenance people, laboratory charges, depreciation, taxes, and insurance costs. Labour cost required in the processing of broccoli stalks is dependent on the automation of the facility and on the local labour availability and wage conditions [33]. The minimum wage in Quebec in 2016 is CAD 10.75 per hour. Laboratory cost is needed for process monitoring and quality control. The cost for supervision can be estimated as 20% of the cost of the operating labour. Whereas, the plant overhead charges are estimated as 50% of the labour cost.

Table 2: Capital costs estimation for the broccoli stalks processing facility in Quebec, Canada.

| Component                          | Estimated Cost (CAD) |
|------------------------------------|----------------------|
| **Direct cost (DC)**               |                      |
| Purchased equipment cost (PEC)     | 60,465               |
|  - Washer & Peeler (Capacity: 125 kg/h) |                    |
|  - Slicer (Capacity: 110 kg/h)     |                      |
|  - Osmotic dehydration unit (Capacity: 100 kg/h) |        |
|  - Dryer (Capacity: 40 kg/h)       |                      |
|  - Packaging unit (Capacity: 15 kg/h) |                    |
| Insulation (39% PEC)               | 23,581               |
| Instrumentation & control (13% PEC)| 7,860                |
| Piping (31% PEC)                   | 18,744               |
| Electrical equipment and materials (10% PEC) | 6,046         |
| Building (29% PEC)                 | 17,535               |
| Yard Improvement (10% PEC)         | 6,046                |
| Land (6% PEC)                      | 3,628                |
| Service facilities (55% PEC)       | 33,256               |
| **Total DC**                       | 177,162              |
| **Indirect cost (IC)**             |                      |
| Design and Engineering (25% DC)    | 44,291               |
| Contractor fees (18% DC)           | 31,889               |
| Contingency (10% DC)               | 17,716               |
| **Total IC**                       | 93,896               |
| **Fixed capital cost (FCI) = DC+IC** | 271,058             |
There are administrative costs associated with the maintenance and operation of the facility and it will be a part of general expenses that determine the product cost. Finally, there will be distribution and selling costs, at about 2% of the total operating cost, associated with the final product price. The estimation of total operating costs is shown in Table 3.

The profitability assessment of a production process is performed based on the return on investment (ROI) and payback period (PBP) calculations. The ROI is calculated by dividing the expected profit by total capital investment incurred and expressed as a percentage [34]. The PBP is the number of years it may take to recover the initial cost incurred at the start of a production operation. The payback period can be calculated as shown in Equation (3) [30].

\[
PBP = \frac{\text{Fixed capital investment}}{\text{Net profit} + \text{Depreciation}}
\] (3)

The sale price, including a minimum profit of 20%, of the dried broccoli stalk slices, produced in a facility that processes about 333.8 metric tonnes of broccoli stalks to 30.8 tonnes of dried products, is found to be CAD 23.8/kg. Thus, after tax, the net annual earning is calculated to be CAD 106,756. Thereby, the ROI is computed to be 34.3% and the PBP is found to be about 2.03 years.

3.6 Environmental benefits

The global wastage of food is estimated as 1.3 billion tonnes per year. The decomposition of this waste is associated with the release of about 3.3 billion tonnes of CO₂ equivalent greenhouse gases per year globally [vii]. This emission contributes to global warming and the associated catastrophes and economic damages [1,35]. Diverting broccoli stalks, that otherwise would have end up directly in the landfill sites, into a nutritious food source, will reduce the GHG emissions and thus save environment and benefits economy. However, the economic benefits available through the reduction in GHG emissions is practically difficult to estimate [1] and possibly one of the practical ways is by considering the carbon credit associated with the projects that reduce GHG emissions. Since the conversion of broccoli stalks into food products can reduce the emission of GHG gases, it can be used to claim and trade carbon credit to gain additional economic benefits [36].

4. Conclusions

In view of improving the food security and harnessing the climate change, innovative use of food resources should be developed and practiced. Broccoli stalk is an underutilized but nutrient rich material that can be processed as food material using advanced processing methods like the combined osmotic dehydration and microwave-assisted hot air drying. The integration of these individual processes results in about 68% reduction in energy input required in the preparation of dried broccoli stalk slices when compared to the stand-alone microwave-assisted drying. The ROI of 34.2%, 2 years of PBP and environmental benefits point to the economic feasibility of this process. Thus, the production of edible products from waste material like broccoli stalks has apparent economic and environmental benefits.

Nomenclature

- **Q**: Heat energy, J
- **m**: Mass, kg
- **Cp**: Specific heat capacity, J·kg⁻¹·℃⁻¹ (J·kg⁻¹·K⁻¹)
- **T**: Temperature, ℃(K)

Table 3 Summary of annual operating costs to produce osmo-dried broccoli stalk slices in Quebec, Canada.

| Component                          | Estimated Cost (CAD) |
|------------------------------------|----------------------|
| **Variable costs**                 |                      |
| Raw materials                      | 253,935              |
| Utilities                          | 7,650                |
| Packaging material                 | 67,314               |
| Sub-total A                        | 328,899              |
| **Fixed costs**                    |                      |
| Maintenance (6% FCI)               | 16,263               |
| Operating labour                   | 103,200              |
| Laboratory cost (20% Operating labour) | 20,640         |
| Supervision (20% Operating labour) | 20,640               |
| Plant overheads (50% Operating labour) | 51,600           |
| Depreciation (10% FCI)             | 27,106               |
| Local taxes (2% FCI)               | 5,421                |
| Insurance (1% FCI)                 | 2,711                |
| Sub-total B                        | 247,581              |
| **Direct production cost (A+B)**   | 576,480              |
| **General expense**                |                      |
| Administrative                     | 21,016               |
| Distribution and selling           | 12,194               |
| Sub-total C                        | 33,209               |
| **Annual operating cost = A+B+C**  | 609,689              |
CP: Processing capacity, kg · h⁻¹
λ : Latent heat of water vaporization, kJ · kg⁻¹
Δ : Difference in quantities

Acknowledgements

The authors are grateful to Natural Sciences and Engineering Research Council of Canada (NSERC) for the financial support of this study and to Ministry of Higher Education Malaysia and Universiti Malaysia Terengganu for the granted scholarship to the first author.

References

1) H. C. J. Godfray, J. R. Beddington, I. R. Crute, L. Haddad, D. Lawrence, J. F. Muir, J. Pretty, S. Robinson, S. M. Thomas, C. Toulmin; Food security: The challenge of feeding 9 billion people. Science, 327(5967), 812–818 (2010).
2) R. Mendelsohn; The impact of climate change on agriculture in Asia. J. Integr. Agric., 13, 660–665 (2014).
3) S. Nonhebel, T. Kastner; Changing demand for food, livestock feed and biofuels in the past and in the near future. Livest. Sci., 139, 3–10 (2011).
4) V. Orsat, W. Yang, V. Changrue, G. S. V. Raghavan; Microwave-assisted drying of biomaterials. Food Bioprod. Process., 85, 255–263 (2007).
5) G. R. Askari, Z. Emam–Djomeh, S. M. Mousavi; Heat and mass transfer in apple cubes in a microwave–assisted fluidized bed drier. Food Bioprod. Process., 91, 207–215 (2013).
6) R. Borquez, D. Melo, C. Saavedra; Microwave–Vacuum Drying of Strawberries with Automatic Temperature Control. Food Bioprocess Tech., 8, 266–276 (2015).
7) X. Duan, L.–l. Huang, M.–m. Wang, F. Qiao, C.–f. Fang; Studies on the Effects of Microwave Power and Temperature Control on the Quality of Whole Lychee (Litchi chinensis Sonn.) Fruit during Microwave Vacuum Drying. J. Food Process. Pres., 39, 423–431 (2015).
8) D. Kumar, S. Prasad, G. S. Murthy; Optimization of microwave–assisted hot air drying conditions of okra using response surface methodology. J. Food Sci. Tech., 51, 221–232 (2014).
9) S. Gunasekaran; Pulsed microwave–vacuum drying of food materials. Drying Tech., 17, 395–412 (1999).
10) N. S. Md Salim, Y. Gariépy, V. Raghavan; Effects of operating factors on osmotic dehydration of broccoli stalk slices. Cogent Food & Agriculture, 2, 1134025 (2016).
11) G. S. V. Raghavan, V. Orsat; “Nonconventional Heating Sources during Drying”, Advances in Food Dehydration, CRC Press, 2008, pp. 401–422.
12) K. Tadeusz; “Energy Aspects in Food Dehydration”, Advances in Food Dehydration, R. Cristina Ed., CRC Press, Boca Raton, FL, USA, 2008, pp. 423–445.
13) N. Nimmanpipug, N. Therdthai, P. Dhamvithee; Characterisation of osmotically dehydrated papaya with further hot air drying and microwave vacuum drying. Int. J. Food Sci. Tech., 48, 1193–1200 (2013).
14) N. Therdthai, W. Zhou, K. Pattanapa; Microwave vacuum drying of osmotically dehydrated mandarin cv. (Sai-Namphang). Int. J. Food Sci. Tech., 46, 2401–2407 (2011).
15) D. Zhao, C. Zhao, H. Tao, K. An, S. Ding, Z. Wang; The effect of osmosis pretreatment on hot–air drying and microwave drying characteristics of chili (Capsicum annuum L.) flesh. Int. J. Food Sci. Tech., 49, 185–191 (2001).
16) E. Torringa, E. Esved, I. Scheewe, R. van den Berg, P. Bartels; Osmotic dehydration as a pre–treatment before combined microwave–hot air drying of mushrooms. J. Food Eng., 49, 185–191 (2001).
17) V. Changrue, V. Orsat; Osmotically dehydrated microwave vacuum drying of carrots. Can. Biosyt. Eng., 51, 311–319 (2009).
18) N. S. Md Salim, Y. Gariépy, V. Raghavan; Microwave–assisted Hot Air Drying Characteristics of Osmotically Dehydrated Broccoli Stalk Slices. Proceedings of the 19th International Drying Symposium, August 24–27, 2014, Lyon, France. Université Claude Bernard Lyon, (2014).
19) V. Zvalo, A. Respondek; “Vegetable crops production guide for Nova Scotia”, Vegetable Production Guide – Broccoli, Vol. 2016, Agra Point, Nova Scotia, 2007.
20) Statistics Canada; Table 001–0013: Area, production and farm gate value of vegetables, annual, Vol. 2016, CANSIM, (2015).
21) Statistics Canada; “Farm data and farm operator data”, Number of farms, farm area, and average farm size by province, with percentage change since 2006, Canada and the provinces, Vol. 2016. (2012).
22) A. E. D. Bekhit, K. Lingming, S. L. Mason, J. H. Zhou, J. R. Sedcole; Upgrading the utilization of brassica wastes: physicochemical properties and sensory evaluation of fermented brassica stalks. Int. Food Res. J., 20, 1961–1969 (2013).
23) E. García-Martínez, J. Martinez-Monzó, M. M. Camacho, N. Martínez-Navarrete; Characterisation of reused osmotic solution as ingredient in new product formulation. Food Res. Int., 35, 307–313 (2002).
24) D. Wray, H. S. Ramaswamy; Recycling of osmotic solutions in microwave–osmotic dehydration: product quality and potential for creation of a novel product. J. Sci. Food Agric., (2016).
25) D. Wray, H. S. Ramaswamy; Recycling of osmotic solutions in microwave–osmotic dehydration: product quality and potential for creation of a novel product. J. Sci. Food Agric., (2016).

26) A. A. Aachary, S. G. Prapulla; Value addition to spent osmotic sugar solution (SOS) by enzymatic conversion to fructooligosaccharides (FOS), a low calorie prebiotic. Innov. Food Sci. & Emerg. Technol., 10, 284-288 (2009).

27) A. Morales, M. Castaño, D. Sinuco, G. Camacho, C. Duque; Dewatering–Impregnation–Soaking (DIS) in non–conventional solutions as source of natural flavorants of Colombian varieties of mango (Mangifera indica) var. Azúcar and pineapple var. Perolera. Food Flavour and Chemistry, Explorations into the 21st century, 231–239 (2005).

28) J. Shi, J. Xue; "Application and development of osmotic dehydration technology in food processing", Advances in food dehydration, C. Ratti ed., CRC Press, Boca Raton, FL, USA, 2009, p. 20.

29) B. A. Stewart, T. A. Howell; "Encyclopedia of water science", Marcel Dekker, New York, 2003.

30) G. Masresha; "Effect of process conditions on osmotic dehydration of Adama red onion slice production", Addis Ababa University, Ethiopia, (2015).

31) C. W. Lamb Jr., P. M. Dunne; "Theoretical developments in marketing", Marketing Classics Press, Arizona State University, (2011)

32) S. Robert; "Microwave and Dielectric Drying", Handbook of Industrial Drying, Third Edition, CRC Press, (2006).

33) M. Dudbridge; "Starting to Measure and Quantify Performance", Handbook of Lean Manufacturing in the Food Industry, Wiley–Blackwell, 2011, pp. 38–61.

34) M. S. Ray, D. W. Johnston; Chemical engineering design project: a case study approach. 1989, New York: Gordon and Breach Science Publishers.

35) A. Carlsson–Kanyama; Climate change and dietary choices — how can emissions of greenhouse gases from food consumption be reduced? Food Policy, 23, 277–293 (1998).

36) D. Bosch, K. Stephenson, G. Groover, B. Hutchins; Farm returns to carbon credit creation with intensive rotational grazing. J. soil water conserv., 63, 91–98 (2008).

URLs cited

i) https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf (Aug. 10, 2015).

ii) www.fao.org/docrep/014/mb060e/mb060e.pdf (Aug. 28, 2015).

iii) http://newclimateeconomy.report/wp-content/uploads/2015/02/WRAP-NCE_Economic-environmental-gains-food-waste.pdf (Aug. 28, 2015).

iv) www.fao.org/docrep/018/i3347e/i3347e.pdf (Aug. 28, 2015).

v) https://webofknowledge.com (Aug. 29, 2015).

vi) publications.gc.ca/collections/collection_2009/agr/A118-10-9-2005E.pdf (Aug. 15, 2015).

vii) www.fao.org/docrep/018/i3347e/i3347e.pdf (Aug. 28, 2015).