



Research article

Effect of oven and intermittent airflow assisted tray drying methods on nutritional parameters of few leafy and non-leafy vegetables of North-East India

Imdadul Hoque Mondal^a, Latha Rangan^{a,b}, Ramagopal V.S. Uppaluri^{a,c,*}^a Centre for Rural Technology, Indian Institute of Technology, Guwahati, 781039, India^b Department of Biosciences & Bioengineering, Indian Institute of Technology, Guwahati, 781039, India^c Department of Chemical Engineering, Indian Institute of Technology, Guwahati, 781039, India

ARTICLE INFO

Keywords:

Food engineering
 Food technology
 Food processing
 Food analysis
 Food composition
 Oven drying
 Tray drying
 Proximate analysis
 Vitamin C
 Antioxidant activity

ABSTRACT

Given a sizable proportion of bio-resource production in the North-east (NE) India and the need to enhance the shelf life of perishable horticultural regional produce, this work addresses the optimality of inexpensive oven and intermittent airflow assisted tray drying processes for Kolmou (*Ipomoea aquatica* Forssk.), Pui (*Basella alba*), Jatialao sak (*Lagenaria siceraria* leaves), Kolphul (*Musa balbisiana* Colla blossom), Kaskal (*Musa splendida*), green Komora (*Benincasa hispida*) and Posola (*Musa balbisiana* Colla pseudostem) vegetables of NE India. Characterization parameters for process parametric optimality include proximate analysis based evaluation of moisture content, yield, carbohydrate, crude protein, soluble protein, vitamin C, antioxidant activity, ash, crude fibre and fat content. For most vegetables, tray drying process performance is superior in terms of better moisture removal, higher yield and higher anti-oxidant activity. Among all considered samples, tray dried Kolmou possessed highest antioxidant activity. Vitamin C content was seen to be highest in tray dried Komora.

1. Introduction

Located in the latitudes and longitudes of 21.5–29.5° N and 85.5–97.3° E, North-east India (NE) is characterized as a world biodiversity hotspot and unique agro-climatic zone of India. Being a bounty region of natural vegetation, the region is home to many endemic leafy, non-leafy wild and conventional vegetables. The wild endemic vegetables constitute a significant proportion of the total vegetable produce in the region. Further, the inhabitation of various ethnic tribes in different regions of NE India is responsible for a distinct food cuisine, diet system and food habitat with wild and ethnic horticultural produces. According to NHB and State Departments, 2010–11, the NE India produces 6.79% of total horticultural produce in India of which vegetables alone occupies 51.83%.

Leafy and non-leafy vegetables are well known for their nutritional contributions to the human diet. Besides being a rich source of carbohydrates, fibre, minerals and vitamins, these horticultural produces also possess good quantities of protein, phytochemicals and antioxidants which are all good features associated to a healthy produce for human consumption. With high moisture content, vegetables are susceptible for

microbial attack and hence are highly perishable entities. Apart from this, many vegetables are seasonal and long-term storage is a very important issue from the perspective of consumption. Hence, shelf life is reduced significantly from the time of production. Horticultural processing facilitates longer shelf life and eases their transport to distant places, thereby converting them into value-added products such as ready to eat or cooked foods.

Among various alternatives for the preservation of leafy and non-leafy vegetables, drying technology is the most versatile in terms of being low cost, a high degree of scalability, ease of operation and ability to preserve wide varieties of vegetables. Drying facilitates moisture removal from food resources and was traditionally followed as sun drying from an age-old time. Moisture removal by this conventional practice is due to the differences in the vapour pressure of the food materials and surrounding environment driven by heat. Further, drying facilitates removal of moisture from both surface and inner portions of the vegetables by channel formation for vapour removal throughout the system. In addition, drying prevents spoilage due to microbial attack and thereby facilitates dried products having a good shelf life to be available throughout the year without loss of appropriate nutrient constitution.

* Corresponding author.

E-mail address: ramgopal@iitg.ac.in (R.V.S. Uppaluri).

Alternate drying techniques include the sun, tray, oven, shadow drying etc, all of which significantly influences the quality of the dried products. It is well known that shadow drying is slow and sun drying is detrimental to retain nutritional parameters in vegetables. Several nutritional constituents are sensitive towards heat treatment and drying environment. Therefore, it is very important to choose appropriate drying method to retain maximum nutritional constituents of the vegetables. Also, the drying characteristics of leafy and non-leafy vegetables is significantly influenced with many drying process parameters such as air velocity, intermittency extent of air flow, sample thickness, moisture relative humidity, temperature and time. Among these, temperature and time are the most relevant parameters and upon their conceptual optimization all other parameters such as sample size, thickness, and airflow can be optimized for best process. The available literature is fairly indicative towards this research theme. [Satwase et al. \(2013\)](#) studied the drying effect on proximate values of drumstick leaves using shadow, sun, oven and tray drying methods. The tray drying process facilitated better preservation of nutrients. Among sun, oven, tray and freeze drying methods, [Ariola et al. \(2009\)](#) concluded that oven drying was the best during drying of unripe banana plantain (*Musa paradisiaca*).

Few investigations have been carried out for some of the targeted leafy and non-leafy vegetables of NE India in the current study. These refer to Kolmou (*Ipomoea aquatica* Forssk.), Pui (*Basella alba*), Jatilao sak (*Lagenaria siceraria* leaves), Kolphul (*Musa balbisiana* Colla blossom), Kaskal (*Musa splendida*), green Komora (*Benincasa hispida*) and Posola (*Musa balbisiana* Colla pseudostem) vegetables of NE India. The oven drying of Kolmou (*Ipomoea aquatica* Forssk.) and Jatilao leaves (*Lagenaria siceraria* leaves), cabinet drying of Pui (*Basella alba*) were carried out by [Satter et al. \(2015\)](#), [Karmakar et al. \(2013\)](#) and [Tongco et al. \(2015\)](#) respectively. The authors characterized Kolmou and Pui in terms of proximate parameters. On the other hand, Jatilao leaves were analysed for ash, ascorbic acid, and iron content. Similarly, Banana pseudostem (*Musa balbisiana* Colla) was dried using cabinet drying at 50 °C by [Ma et al. \(2016\)](#) to evaluate their proximate parameters. Comparative effect of oven and tray drying on nutritional quality parameters like proximate values, vitamin C and antioxidant activity were not investigated on the targeted samples. A critical insight into the above-summarized literature conveys that while several investigations have been conducted to indicate optimality of alternate drying techniques of leafy and non-leafy vegetables, few other investigations that were reported for the targeted vegetables in this work were examined for nutritional analysis using only one single drying method. In summary, the targeted leafy vegetables (Kolmou (*Ipomoea aquatica* Forssk.), Pui (*Basella alba*), Jatilao sak (*Lagenaria siceraria* leaves)) and non-leafy vegetables (Kolphul (*Musa balbisiana* Colla blossom), Kaskal (*Musa splendida*), green Komora (*Benincasa hispida*) and Posola (*Musa balbisiana* Colla pseudostem)) that are abundantly available in the NE India region were not investigated in terms of optimality of various drying methods. This is very important to select the most competent method for large-scale processing of abundant vegetable produces and facilitate ready to eat/cook food formulations from these vegetables. Among alternate drying methods, oven and tray drying can be regarded as the most versatile technologies in NE India. This is also due to the fact that NE India has average solar incidence parameter and hence solar/sun drying could be time-consuming and disadvantageous to the region as a continuous and sustainable energy source. In summary, from a cost competitiveness perspective, tray, sun, shade, and oven drying processes are inexpensive than freeze and vacuum drying processes. In NE India, due to the availability of moderate infrastructure, tray and oven drying can be regarded to be most competitive in terms of minimal capital investment and operating costs. While in oven drying, there is a natural circulation of air that facilitates the removal of moisture from the sample. While the natural circulation of air is not significant to promote effective mass transfer, it is effective to a fair extent to facilitate vapour pressure difference between the oven environment and sample at the prevalent temperature. On the other hand, tray drying uses heat and airflow to dry the leafy and non-leafy

vegetables. Thus, tray drying facilitates variant humidity characteristics of the environment due to airflow, which is not the case during oven drying. The intermittent air flow during tray drying further reduces the energy consumption of the blower. All these could have a significant effect on the nutritional characteristics of dried products.

With an intention to assist food processing industries in NE region like soup making and vegetable processing industries, this work addresses the comparative assessment of oven and intermittent airflow assisted tray drying methods for the chosen leafy and non-leafy vegetables. The ultimate objective of the chosen vegetables is to develop competent soup formulations for ready to eat/cook product development. Such research is on the rise in states such as Maharashtra of India. All-important parameters have been considered for evaluation.

2. Materials and methods

2.1. Raw materials

Raw leafy and non-leafy vegetables were procured from Shingimari area, Kamrup, Assam, India (26.2205° N and 91.6241° E). The vegetables were carried in a tightened polyethylene pouches to avoid external contamination during transport. Leafy vegetables include Kolmou (*Ipomoea aquatica* Forssk.), long Jatilao leaves (*Lagenaria siceraria* leaves) and red stalk Pui (*Basella alba*). Non-leafy vegetables included in the current study are Kolphul (*Musa balbisiana* Colla blossom) and Posola (*Musa balbisiana* Colla pseudostem) from Bhimkal variety, Kaskal (*Musa splendida*) and green Sal Komora (*Benincasa hispida*).

2.2. Chemicals

Sodium hydroxide pellets, oxalic acid dehydrate, sulfuric acid (98%), dextrose, absolute methanol and petroleum ether were procured from Merck India; Anthrone extrapure, 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) extrapure and 2, 6-dichlorophenol indophenol sodium salt (DCPIP) were bought from SRL Pvt. Ltd., India; sodium bicarbonate, Bovine Serum Albumin and Bradford Reagent were purchased from Rankem, SRL and Sigma Aldrich, India respectively.

2.3. Sample preparation

Fresh leafy and non-leafy vegetables were sorted and washed in tap water to remove the dust and other adhering contaminants. Subsequently, the vegetables were thoroughly rinsed to remove the excess water. Leafy vegetables were detached from the stalk and placed in single layer on trays for drying. Average sizes (length×width) of Kolmou, Jatilao and Pui were 8.5 cm × 3 cm, 11 cm × 13.5 cm and 11.5 cm × 8.5 cm respectively. The non- leafy vegetables such as Posola, Kaskal and Komora were cut into circular slices (thickness 1mm and diameters of 5, 3.5 and 8 cm respectively) and kept in a single layer on trays for drying. For the Kolphul, outermost two to three bracts and their edible portion were removed and subsequent blossoms were used. The edible blossoms were removed from the bracts and lower bases were cut vertically into two equal parts as drying samples. The average size (length × width × thick) of Kolphul was 8.6 cm × 0.5 cm × 0.01 cm.

2.4. Drying methods

Laboratory scale oven (REICO) was deployed to dry leafy and non-leafy vegetable samples in trays at 60 °C for 4 and 10 h respectively. The dried samples were grounded for further analysis. The tray drying involved drying of leafy and non-leafy vegetables at a constant air velocity of 4.5 m/s with an automatic intermittent airflow (20 s in run and 20 s in off-mode) at 60 °C for 4 and 10 h respectively in a laboratory tray drier. Since lower continuous airflow mode would provide better drying characteristics, higher flow rate has been considered in intermittent air flow mode of operation, given the fact that the stationary phase of

operation may detriment moisture removal from primarily leafy vegetable samples. The extent of intermittency of airflow is a very important parameter to influence the drying characteristics of leafy and non-leafy vegetables using tray drying system. The chosen value of 20s/20s stationary/run mode is based on the presumption that similar range of intermittency would enable bettering equilibrium in the sample and retention of nutritional characteristics. The temperature and time combination significantly influences the drying characteristics of leafy and non-leafy vegetables using tray and oven drying processes. Based on extensive literature survey (Satwase et al., 2013; Joshi and Mehta, 2010; Sahoo et al., 2014; Gupta et al., 2013), 60 °C is regarded to be the optimal temperature for most horticultural produces. Also, preliminary investigations indicate that the drying time for leafy and non-leafy vegetables vary from 3–5.5 and 8–12 h respectively as the nutritional content and moisture content of the samples varied significantly in the above time range. Thus, based on literature survey and trial and error approaches, the average drying time has been set as 4 and 10 h for leafy and non-leafy vegetables in this work. After drying, the samples were grounded for further analysis.

2.5. Determination of nutritional parameters

2.5.1. Yield

The yield was determined by measuring the weight of samples before and after oven/tray drying. Yield is evaluated using the expression:

$$\text{Yield (\%)} = \frac{W_s}{W_f} \times 100 \quad (1)$$

where W_f and W_s are the weights of fresh and oven/tray dried sample respectively.

2.5.2. Moisture content

The moisture content of the oven/tray dried samples was determined using AOAC 2010 method (AOAC, 2010). A known amount of sample was taken in a glass petri dish and was kept in an oven overnight at 105 °C. Subsequently, the sample was cooled in a desiccator and weighed. The expression (AOAC, 2010) to determine moisture content is:

$$\text{MC (\%)} = \frac{W_s - W_d}{W_s} \times 100 \quad (2)$$

where W_d and W_s are the weight of sample taken and dried sample (105 °C) respectively.

2.5.3. Ash content

The ash content was determined with AOAC 2010 method (AOAC, 2010). The known amount of vegetable samples were placed in a muffle furnace at 600 °C for 6 h. After cooling in desiccator weight of remaining residue (ash) was taken. Thereby, the ash content is determined using the expression (AOAC, 2010):

$$\text{Ash (\%)} = \frac{W_a}{W_s} \times 100 \quad (3)$$

where W_a and W_s are the weight of ash and sample taken respectively.

2.5.4. Crude fibre content

Crude fibre content was determined using the method summarized by Sadasivam and Manikam (1992) whose procedure is presented as follows. Firstly, 1g of dried sample was added to 100 mL of 1.25% H_2SO_4 and boiled for 30 min under constant stirring condition using a magnetic hot plate setup. Thereby, the sample was filtered with muslin cloth and washed with boiling water to make it free from acid. Subsequently, the residue was given similar treatment with 1.25% NaOH and was filtered and washed with boiling water. The obtained residue was washed again

with boiling 1.25% H_2SO_4 , 50 mL water and 25 mL of alcohol. Thereafter subsequent washing, the residue was kept in a crucible and placed in an oven at 130 ± 2 °C for 2 h. The sample was eventually cooled in a desiccator and weighed. The sample was then transferred to a muffle furnace at 600 °C for 30 min to undergo ignition. Thereafter, the sample was cooled and weighed to determine the crude fibre content using the expression (Sadasivam and Manikam, 1992):

$$\text{Crude Fibre (\%)} = \frac{W_l}{W_s} \times 100 \quad (4)$$

where W_l and W_s are the weight loss during ignition in a muffle furnace at 600 °C and the sample taken initially respectively.

2.5.5. Fat content

The AOAC 2010 method (AOAC, 2010) was followed to determine the fat content of the vegetable sample. The method involved placing the known amount of dried sample in a thimble and subsequent extraction in the Soxhlet apparatus using petroleum ether. Finally, the petroleum ether was evaporated and the amount of fat was determined using the equation (AOAC, 2010):

$$\text{Fat (\%)} = \frac{W_f}{W_s} \times 100 \quad (5)$$

where W_f and W_s are the weight of treated and sample taken respectively.

2.5.6. Soluble protein content

The soluble protein content was determined using Bradford's method (Bradford, 1976). About 100 mg of dried sample was dissolved in 100 mL of distilled water using mortar and pestle. Thereafter, 1 mL of the extract was taken and 5 mL Bradford's reagent was added to the system. The mixture absorbance was measured at 595 nm using BSA standard and UV-Visible spectrophotometer (Model No.: UV-2600, Make: Shimadzu, Singapore).

2.5.7. Carbohydrate content

The carbohydrate content of various samples was determined by Clegg anthrone method (Okonwu and Enyinnaya, 2016). The involved procedures are summarized as follows. Firstly, 1g of the sample was added to 10 mL of distilled water and was thoroughly stirred. Thereafter, 13 mL of 62% perchloric acid was added and the mixture was continuously stirred for 20 min. After further dilution of the mixture up to 250 mL, the mixture was filtered through glass filter paper. Eventually, 10 mL of the filtrate was diluted to 100 mL with distilled water and 1 mL of diluted filtrate was mixed with 5 mL of anthrone reagent. Blank samples were also prepared by adding 5 mL anthrone reagent with 1 mL distilled water. Subsequently, both samples were kept in a water bath for 12 min at 100 °C. Finally, the absorbance of the samples (both blank/standard and vegetable-based sample) were measured at 630 nm. The carbohydrate content of the vegetable sample was determined using the expression (Okonwu and Enyinnaya, 2016):

$$\text{Carbohydrate (\%)} = \frac{A_s}{A_{std}} \times 25 \quad (6)$$

where A_s and A_{std} are the absorbance of the diluted sample and the standard (blank).

2.5.8. Crude protein content

The crude protein content was determined using the difference method and was calculated using the following expression:

$$\text{Crude protein (\%)} = 100 - (\text{moisture} + \text{carbohydrate} + \text{fat} + \text{crude fibre}) \quad (7)$$

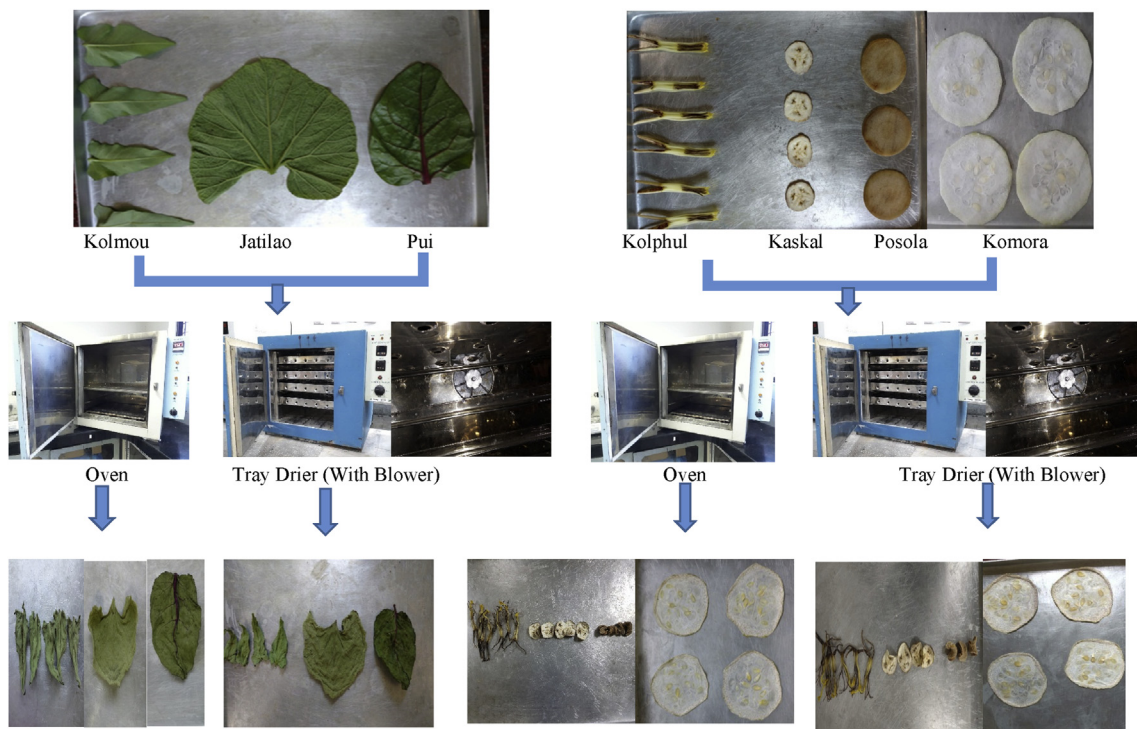


Figure 1. Pictorial representation of drying of leafy and non-leafy vegetables.

2.5.9. Vitamin C content

The Vitamin C content was determined using the method followed by Sadasivam and Manickam (1992) described by Anjali et al. (2012) and Ravula et al. (2017). The involved procedure is presented as follows. Firstly, 100 mg of dried sample was extracted with 10 mL 4% oxalic acid using mortar and pestle. Thereafter the sample was centrifuged and the supernatant was collected for further experimentation. About 5 mL of the supernatant was pipetted and mixed with 10 mL of 4% oxalic acid. The mixture was titrated with 2, 6-dichlorophenol indophenol dye solution. Ascorbic acid was taken as the standard in the titration experiments. Thereby, the Vitamin C content was determined using the equation (Sadasivam and Manickam, 1992):

$$Vitamin\ C\ (mg/100g) = \frac{.5 \times V_2 \times 10 \times 100}{V_1 \times 5 \times W_s} \tag{8}$$

where V_1 and V_2 are the millilitre of ascorbic acid and sample extract consumed and W_s corresponds to the weight of the sample taken.

2.5.10. Antioxidant activity

2,2-diphenyl-1-picrylhydrazyl (DPPH) assay procedures reported by Barimah et al. (2017), Sana et al. (2014) and Sochor et al. (2010) was

followed to determine the antioxidant activity of the vegetable samples. The involved procedure is briefly presented as follows. Firstly, 10 mg of each sample was extracted with 20 mL of absolute methanol for 30 min in a sonicator (model: Elmasonic S 30 H, make: Elma) and was thereby filtered through Whatman no.1 filter paper. About 1 mL extract was pipetted out added with 3 mL of 0.002% methanolic DPPH solution. Control was prepared by adding 3 mL of the methanolic DPPH solution to 1 mL methanol. Thereafter, the samples were shaken and incubated in dark for 30 min. Finally, the absorbance of the samples (both control and processed) absorbance was measured at 517 nm using UV spectrophotometer. Using measured absorbance values, the antioxidant activity of the samples was determined using the expression (Barimah et al., 2017; Sana et al., 2014; Sochor et al., 2010):

$$AA = \frac{A_c - A_s}{A_c} \times 100 \tag{9}$$

where A_c and A_s correspond to the absorbance of control and sample respectively.

3. Results and discussion

Among the two drying methods, intermittent airflow assisted tray drying provides better quality characteristics than oven drying. Pictorial representation of the drying methods with samples has been presented in Figure 1. The mechanism of vegetable drying during intermittent air flow condition is presented as follows. During flow phase of the air flow, effective moisture removal is facilitated from the sample surface and thereby drives moisture effusion from the core to the surface of the sample. The stationary phase enables equilibration of the moisture at the sample surface and thereby minimizes nutrient loss. Thereby, better efficiency with higher moisture removal, lower stress on nutritional constituents is apparent during intermittent flow mode of operation in comparison with either continuous air flow mode of operation or stagnant air condition. In other words, for similar temperature and time combinations, these mechanisms facilitate better product drying characteristics in terms of nutrient retention and effective moisture removal.

Table 1. Effect of oven and tray drying on yield of (a) leafy and (b) non-leafy vegetables.

Sample/Drying method	Oven	Tray
(a)		
Kolmou	13.29 ± 0.16	13.94 ± 0.21
Pui	10.99 ± 0.53	11.41 ± 0.32
Jatilao	13.15 ± 0.29	14.06 ± 0.36
(b)		
Kolphul	9.26 ± 0.18	10.01 ± 0.09
Kaskal	15.86 ± 0.47	16.64 ± 0.28
Komora	4.25 ± 0.13	4.61 ± 0.4
Posola	5.45 ± 0.25	5.58 ± 0.14

Table 2. Effect of oven and tray drying on moisture content of (a) leafy and (b) non-leafy vegetables.

Sample/Drying method	Oven	Tray
(a)		
Kolmou	5.79 ± 0.08	4.21 ± 0.12
Pui	11.51 ± 0.43	10.44 ± 0.28
Jatilao	9.11 ± 0.12	7.68 ± 0.30
(b)		
Kolphul	8.08 ± 0.17	7.34 ± 0.11
Kaskal	3.54 ± 0.04	4.37 ± 0.13
Komora	8.54 ± 0.19	7.30 ± 0.09
Posola	3.05 ± 0.07	1.56 ± 0.15

On the other hand, during oven drying, the moisture removal is effectively facilitated with the differences in the partial pressure of water vapour in the oven at the prevalent temperature and the partial pressure of moisture in the sample. Thus, the drying kinetics are expected to be slow and due to this, the nutritional characteristics of the samples are bound to be severely influenced after drying.

3.1. Yield

The oven and tray dried yield data for all chosen vegetables have been depicted in Table 1a and b. The yield values varied from 11.41–14.06% and 10.99–13.29% for tray dried and oven dried leafy samples respectively. Among all studied material, Jatilao sak possessed the highest yield (14.06% and 13.29% respectively) and Pui sak had the lowest yield (11.41% and 10.99% respectively). The yield data varied from 4.25–15.86% and 4.61–16.64% for oven and tray dried non-leafy vegetables respectively. The yield trend was in the following order: Komora < Posola < Kolphul < Kaskal for oven dried samples. Highest and lowest yield was obtained for Kaskal (15.86%) and Komara (4.25%) respectively. For tray dried samples, the yield was of the following order: Komara < Posola < Kolphul < Kaskal. Among these, Kaskal and Komora gave highest (16.64%) and lowest (4.61%) yields. The yield data is significantly influenced by the drying environment. Tray drying facilitated with intermittent airflow facilitated better retention of sample constituents and thereby promoted higher yield. During intermittent airflow facilitated tray drying, better heat penetration enabled uniform drying of products and better retention of sample constituents. The intermittent mode of airflow operation facilitates removal of moisture from samples during circulation phase and movement of the moisture to the sample surface during stagnation phase. The direct heating effect was also reduced due to air circulation and this enhanced moisture removal from the sample surface.

3.2. Moisture content

Table 2a and b depicts the variations in moisture content of leafy and non-leafy vegetables for oven and tray drying operations. The initial moisture content of Kolmou, Jatilao, Pui, Kolphul, Kaskal, Komora and Posola refers to 86.65, 87.02, 89.78, 90.72, 84.09, 96.05 and 94.49% (standard deviation < 2) respectively. The graph depicts that significant variation exists for oven and tray dried samples. For all cases, better moisture removal occurred during tray drying. The moisture content of oven and tray dried samples varied from 3.05–11.51% and 1.56–10.44% respectively. Among leafy vegetables, highest and lowest moisture content was found in Pui (11.51%) and Kolmou (4.21%) among dried samples. For the non-leafy vegetables, oven dried Komara (8.54%) and tray dried Posola (1.56%) possessed highest and lowest moisture content respectively. In summary, there is better moisture removal in tray drying than oven drying of the samples. Table 2a and b summarizes that the final moisture content of the leafy and non-leafy vegetables vary from 4.21–

Table 3. Effect of oven and tray drying on ash content of (a) leafy and (b) non-leafy vegetables.

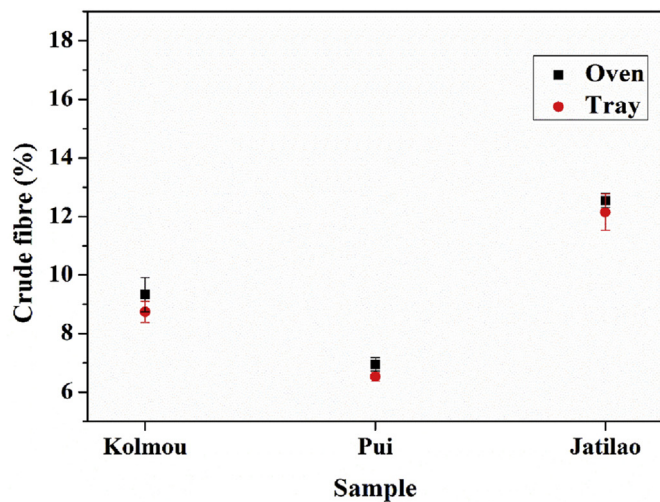
Sample/Drying method	Oven	Tray
(a)		
Kolmou	10.08 ± 0.12	10.98 ± 0.07
Pui	15.26 ± 0.27	16.32 ± 0.18
Jatilao	12.13 ± 0.21	13.88 ± 0.13
(b)		
Kolphul	9.25 ± 0.38	10.84 ± 0.16
Kaskal	4.20 ± 0.08	4.55 ± 0.14
Komora	7.22 ± 0.36	8.22 ± 0.45
Posola	11.72 ± 0.09	12.42 ± 0.15

11.51% and 1.56–8.54% respectively. For safe storage of leafy and non-leafy vegetables the final moisture content has been recommended in the literature to be about 4–10%. Thus, for most of the vegetables, the final moisture content of the leafy and non-leafy vegetables is in the safe range of moisture content for long term storage. For the lone vegetable Pui, the higher final moisture content of 11.51% can be reduced through an increase in drying time by an additional 10%. In summary, all vegetables after tray drying have been inferred to be safe for long term storage. Literature available for moisture content of the targeted samples also shows lower moisture removal than tray drying in the present study (Table 5). This could be due to variations in time and temperature combinations, the drying method used and the source of the samples.

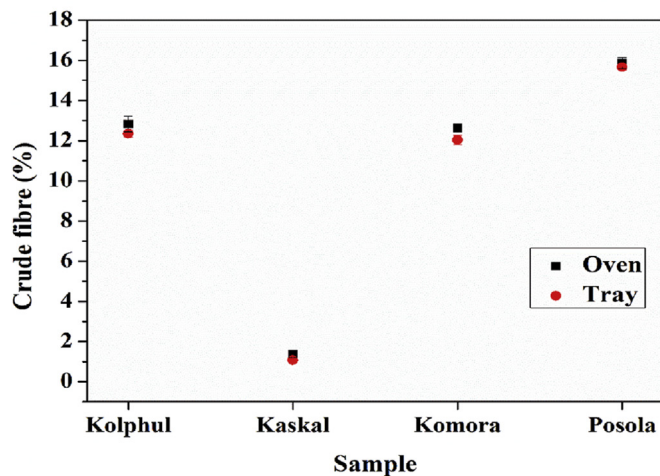
Except Kaskal for which better moisture removal was apparent for oven drying, all other leafy and non-leafy vegetables conveyed lower moisture content for tray dried but not oven dried samples. These general moisture content trends are comparable with Satwase et al. (2013). The exceptional data of Kaskal is compatible with the observations of Arinola et al. (2009) who conducted oven, tray, sun and fluidized bed drying of unripe banana plantain. Similarly, Sakhale et al. (2007) and Kenghe et al. (2015) inferred that tray dried curry leaves possessed lower moisture content than sun and shade dried products. The primary reason for such trends is that while oven drying is deprived of air circulation and facilitates dry heat, the tray drying facilitates drying as well as the better environment in the drying system. Intermittency of airflow facilitates the moisture removal during its flowing phase while moisture accumulates at the surface from inside during its stationary phase owing its better efficiency in removing the moisture. For Kaskal sample, deviant drying characteristics have been obtained i.e., for starchy banana (Kaskal) and tray drying case, moisture removal was marginally lower for similar drying time as that of the oven drying. Arinola et al. (2016) also reported the better efficiency of oven drying than tray drying in removing moisture from unripe banana. This is possibly due to gelatinization of prevalent starch in the sample. For unripe banana, airflow assisted tray drying drastically increases the gelatinization temperature (Khoozani et al., 2019). Hence, the extent of starch gelatinization in the presence of sample moisture was higher in oven drying in comparison with tray drying. This results in softening and bursting of starch granule (gel like liquid) and faster removal of moisture in oven drying. Therefore, compared to oven drying, tray drying has lower moisture removal for similar conditions of drying time and temperature.

3.3. Ash content

Table 3a and b presents the ash content data of leafy and non-leafy vegetables based on tray and oven drying processes. Better retention of ash content was observed for all samples for tray drying facilitated with intermittent airflow. Among all leafy vegetables, Pui in both oven and tray drying (15.26% and 16.32%) was observed to possess high ash content. On the other hand, among non-leafy vegetables, oven and tray dried posola (11.72% and 12.42% respectively) possessed the highest ash



(a)



(b)

Figure 2. Effect of oven and tray drying on crude fibre content of (a) leafy and (b) non-leafy vegetables.

content. Irrespective of drying method, lowest ash content was found in Kaskal (4.20% and 4.55% in oven and tray drying). Among the leafy vegetables, Kolmou possessed the lowest ash content for both oven

(10.08%) and tray (10.98%) dried cases. Highest ash content after tray drying is due to lower moisture content in tray dried samples and the combined effect of heat and intermittent air flow during drying. However, much variation did not exist in the ash content of tray and oven dried samples. This is due to the reason that ash content is less influenced by heat and air flow. [Satwase et al. \(2013\)](#) and [Arinola et al. \(2009\)](#) also found marginal variations in the ash content of tray and oven dried drumstick leaves and unripe banana plantain.

3.4. Crude fibre content

The crude fibre data for the oven and tray dried samples is depicted in [Figure 2a](#) and [b](#). For the tray dried samples, the crude fibre content varied from 1.08-15.67% with the highest crude fibre obtained for Jatilao (12.15%) and Posala (15.67%) among leafy and non-leafy vegetables respectively. Incidentally, lowest fibre content was obtained for Pui (6.53%) and Kaskal (1.08%). On the other hand, the crude fibre content of oven dried vegetables varied from 1.36 to 15.86% with the highest content available in Jatilao sak (12.55%) and Posola (15.86%) among leafy and non-leafy vegetables. These values are in agreement with literature reported values for other vegetables as well. The oven dried samples had higher crude fibre content than tray dried samples and this is in agreement with the trends reported by [Satwase et al. \(2013\)](#). Similar to the results of [Arinola et al. \(2009\)](#), Kaskal possessed close values of crude fibre with tray (1.08%) and oven (1.36%) drying samples. Despite lower values for tray dried samples, the equivalent fibre content is high for all cases and this is due to higher yield and lower moisture content of the samples. Values are also higher than the literature values for most samples as shown in [Tables 4](#) and [5](#) which shows the superiority of tray drying over the drying methods used in literature.

3.5. Fat content

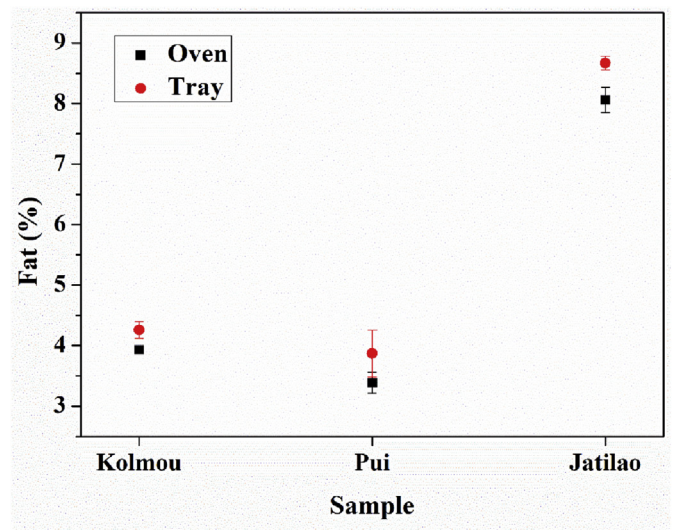
As shown in [Figure 3a](#) and [b](#), the fat content of leafy and non-leafy vegetables is in the order as Jatilao>Kolmou>Pui and Kolphul>Posola>Komora>Kaskal respectively. The highest fat content was obtained for Jatilao sak (8.67% and 8.06% for tray and oven dried samples) followed by Kolphul (8.57% and 8.22% corresponding values respectively). The lowest fat content was obtained for Pui (3.39 and 3.87% for oven and tray drying process) in the leafy vegetables and Kaskal (2.68 and 2.93% corresponding values respectively) among non-leafy vegetables. Due to variations in the sample sources and time-temperature combinations, the obtained values for tray dried samples for few vegetables are marginally different from the values reported in the literature and shows higher fat values in tray drying than the literature values for the most of the samples taken ([Tables 4](#) and [5](#)). The mode of drying had a relatively negligible effect on the fat content and the fat

Table 4. Comparison of literature and present work for leafy vegetables.

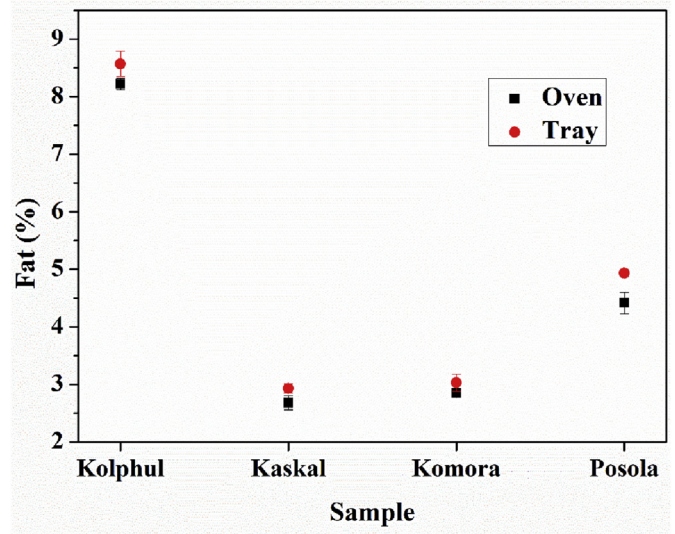
Sl. Sample no.	Drying methods	Optimal Drying and drying conditions	Optimal drying characteristics										Reference	
			Yield (%)	Moisture (%)	Carbohydrate (%)	Protein (%)	Soluble protein (%)	Fat (%)	Fibre (%)	Ash (%)	Vit C (mg/100g)	Antioxidant activity (%)		
1.	Kolmou	Oven and tray drying	Tray drying- 60 °C for 4 h	13.94	4.21	49.27	22.54	10.74	4.26	8.74	10.98	56.96	92.34	This work
2.	Kolmou	Oven	55 °C for constant weight	-	-	52.78	21.45	-	3.34	9.26	9.11	-	-	Satter et al. (2015)
3.	Pui	Oven and tray drying	Tray drying- 60 °C for 4 h	11.41	10.44	46.05	16.8	9.91	3.87	6.53	16.32	123.94	23.08	This work
4.	Pui	Cabinet drying	55 °C for 10 h	-	-	50.62	17.55	-	1.58	7.23	15.49	-	-	Tongco et al. (2015)
5.	Jatilao sak	Oven and tray drying	Tray drying- 60 °C for 4 h	14.06	7.68	39.61	18.02	14.62	8.67	12.15	13.88	112.68	89.45	This work
6.	Jatilao sak	Oven drying	45 °C until constant weight	-	-	-	-	-	-	-	14.50	89.0	-	Karmakar et al. (2013)

Table 5. Comparison of literature and present work for non-leafy vegetables.

Sl. Sample no.	Drying methods	Optimal Drying and drying conditions	Optimal drying characteristics										Reference	
			Yield (%)	Moisture (%)	Carbohydrate (%)	Protein (%)	Soluble protein (%)	Fat (%)	Fibre (%)	Ash (%)	Vit C (mg/100g)	Antioxidant activity (%)		
1	Oven and tray drying	Tray drying-60 °C for 10 h	10.01	7.34	50.52	10.38	8.26	8.57	12.35	10.84	84.51	86.38		This work
2	Kolphul (Musa AAB-Zip Elkon)	Oven drying	-	-	62.19	8.89	-	8.81	-	9.88	-	-		Awedem et al. (2020)
3	Kaskal	Oven and tray drying	16.64	4.37	81.37	5.71	2.99	2.93	1.08	4.55	78.87	60.24		This work
4	Musa paradisiaca	Oven, fluidized bed, tray and oven drying-70 °C for 5 h sun	-	3.24	87.64	3.82	-	1.15	1.04	3.11	-	-		Arinola et al. (2009)
5	Komora	Oven and tray drying	4.61	7.30	62.35	7.05	5.98	3.03	12.04	8.22	304.37	21.36		This work
6	Posola	Oven and tray drying	5.58	1.56	61.19	4.23	3.74	4.93	15.67	12.42	42.25	21.68		This work
7	Banana pseudostem	Cabinet drying	-	4.4	64.4	3.4	-	3.4	-	14	-	-		Ma et al. (2016)



(a)



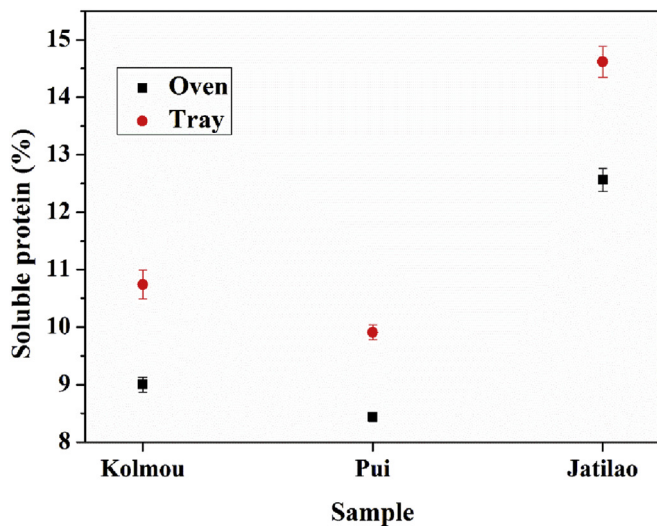
(b)

Figure 3. Effect of oven and tray drying on fat content of (a) leafy and (b) non-leafy vegetables.

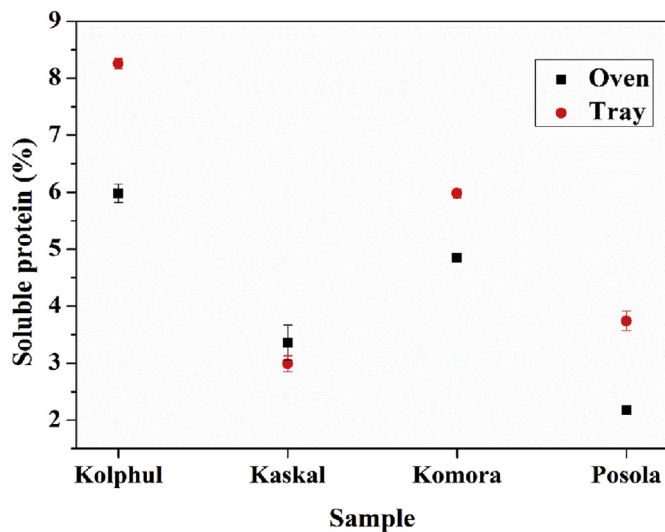
remained intact irrespective of drying methods used. Marginally higher values for the tray dried samples is due to its lower moisture content and higher yield in comparison with oven drying.

3.6. Soluble protein content

A comparative analysis of tray and oven dried samples with respect to soluble protein content is shown in Figure 4a and b. For leafy vegetables, the tray and oven dried samples soluble protein content varied from 9.91-14.62% and 8.44-12.56% respectively. On the other hand, for non-leafy vegetables, these values varied correspondingly from 2.99-8.26% and 2.18-5.98% respectively. Among the leafy vegetables, Jatilao (14.62% and 12.56% in tray and oven drying) and Pui (9.91% and 8.44% in tray and oven drying) exhibited highest and lowest soluble protein content. Among non-leafy vegetables, Kolphul (8.26% in the tray and 5.98% in oven drying) exhibited the highest soluble protein content. Further, it can be analysed that tray dried Kaskal (2.99%) and oven dried Posola (2.18%) had the lowest soluble protein content.



(a)



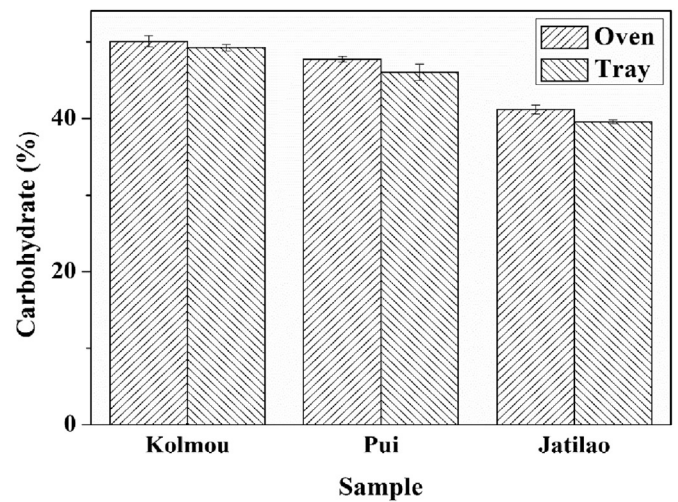
(b)

Figure 4. Effect of oven and tray drying on soluble protein content of (a) leafy and (b) non-leafy vegetables.

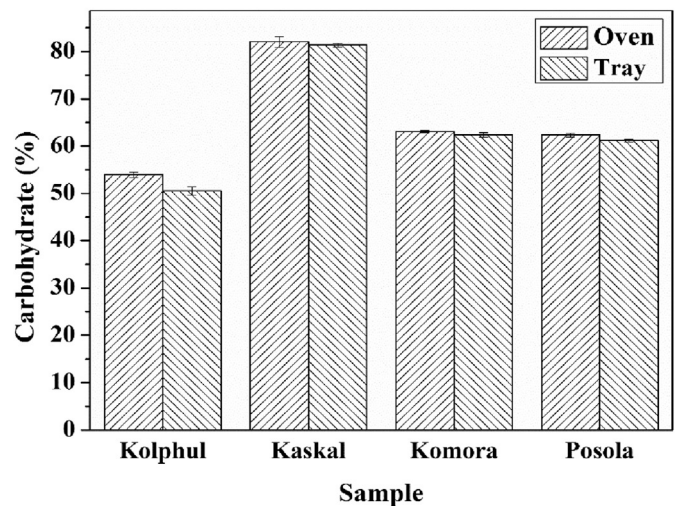
The soluble protein content is found to be high for tray dried but not oven dried samples. Similar views were presented by [Satwase et al. \(2013\)](#) for the protein content of drumstick leaves. Uniform intermittent circulation of air is responsible during tray drying to facilitate higher soluble protein content in the vegetables. Also, it is very likely that oven dried samples are prone to have a reduction in soluble protein content along with the moisture and hence sample moisture content would significantly affect soluble protein content.

3.7. Carbohydrate content

The effect of drying methods on the carbohydrate content of the samples is presented in [Figure 5a and b](#). The carbohydrate content of oven dried leafy and non-leafy vegetables were found to vary from 41.22–51.08% and 53.95–82.06% respectively. For the tray dried samples, these values varied from 39.61 to 49.27% and 50.52–81.37%. Highest carbohydrate content for tray and oven drying method was found in Kaskal (82.06% and 81.37%). Jatilao (41.22% and 39.61% for tray and oven drying) was observed to have the lowest carbohydrate content.



(a)



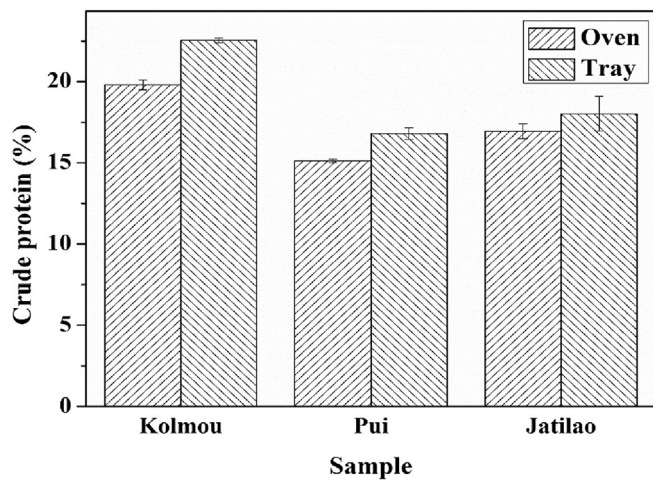
(b)

Figure 5. Effect of oven and tray drying on carbohydrate content of (a) leafy and (b) non-leafy vegetables.

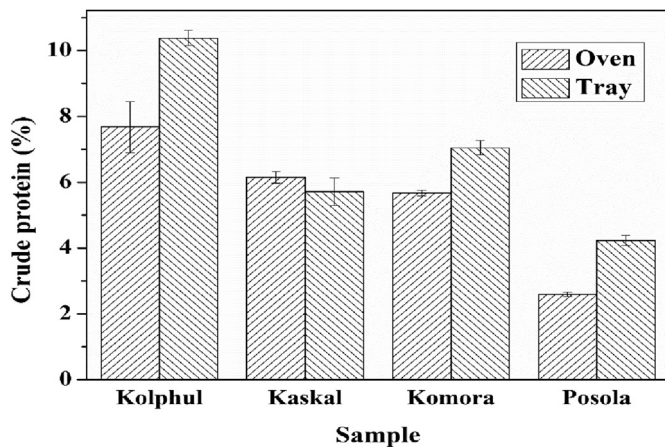
Among the leafy vegetables, Kolmou (51.08% and 49.27% in tray and oven drying) contained the highest amount of carbohydrate in respective drying methods. In general, oven dried samples had higher values than tray dried samples. This is possibly due to the loss of other components during oven drying to simultaneously enhance carbohydrate content per 100 gm of oven dried sample. Similar results were reported for drumstick leaves and banana plantain by [Satwase et al. \(2013\)](#) and [Arinola et al. \(2009\)](#) respectively.

3.8. Crude protein content

[Figure 6a and b](#) summarizes the results obtained for crude protein content. The crude protein of tray and oven dried leafy vegetables varied from 16.80–22.54% and 15.12–19.80% respectively. Corresponding values varied for non-leafy vegetables from 4.23 to 10.38% and 2.59–7.68% respectively. Kolmou (22.54%) followed by Jatilao (18.02%) possessed the highest crude protein among tray dried samples. Similarly, the oven dried Kolmou (19.80%) followed with Jatilao (16.94%) possessed the highest crude protein content among oven dried



(a)



(b)

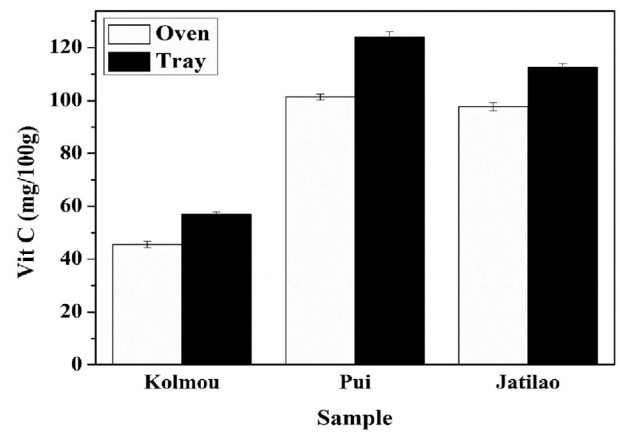
Figure 6. Effect of oven and tray drying on crude protein content of (a) leafy and (b) non-leafy vegetables.

samples. Non-leafy vegetables possessed lower crude protein content with Posola (2.59 and 4.23% for oven and tray dried samples) with the lowest values. The obtained data are consistent with literature reported values. Tables 4 and 5 reveals that crude protein values are higher than the values reported in the literature. This suggests that tray drying is better to achieve higher protein for the samples under consideration. Higher crude protein values obtained for tray but not oven dried samples is also in agreement with the results reported by Satwase et al. (2013) for drumstick leaves. Oven dried Kaskal exhibited higher protein content and this is similar to that reported by Arinola et al. (2009) for banana plantain.

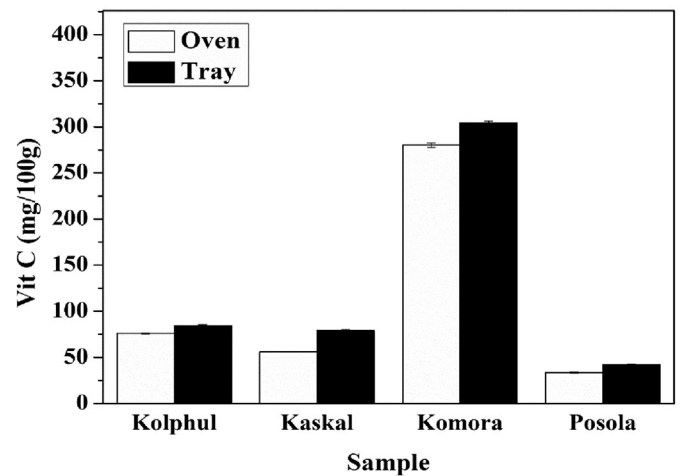
Tables 4 and 5 represents the literature comparison of the parameters for all the samples. As indicated, the protein and fat content are comparably higher than the literature reported values for few cases. These values have been reported as the average value obtained after triplicate experiments and therefore experimental error is ruled out. The higher fat and protein content is probably due to the variations in the species, cultivation methods and climate of the North-east India.

3.9. Vitamin C content

Figure 7a and b depicts the vitamin C content of oven and tray dried samples. For leafy vegetables, these values varied from 56.96 to 123.94 mg/100g and 45.58–101.41 mg/100g for tray and oven dried samples



(a)



(b)

Figure 7. Effect of oven and tray drying on vitamin C content of (a) leafy and (b) non-leafy vegetables.

respectively. Corresponding values for non-leafy vegetables varied from 42.25–304.37 mg/100g and 33.80–280.28 mg/100g respectively. Among the samples, highest vitamin C content was found for tray dried Komora (304.37 mg/100g). Among all vegetables, oven dried Kolmou (55.58 mg/100g) and Posola (33.80 mg/100g) possessed the lowest vitamin C content.

In general, the tray dried leafy and non-leafy vegetables constituted higher vitamin C content in comparison with oven dried samples. As vitamin C is highly sensitive to heat, significant variations in the value exist for each of the samples with the variant mode of drying. Pulsated air circulation mode facilitated better retention of vitamin C in the samples. As hot air flows during flow phase, it picks up the moisture from the sample surface without influencing significantly the heat sensitive constituents of the vegetables. This condition also minimized the heat effect on the samples due to effective moisture removal. The higher values of vitamin C for tray but not oven dried samples are in agreement with the data reported by Saini et al. (2014). The authors reported that tray dried *Moringa oleifera* leaves possessed higher ascorbic acid content than the oven dried samples. Similar views were presented by Kenghe et al. (2015) for tray dried curry leaves in comparison with shade dried leaves.

3.10. Antioxidant activity

Antioxidant activity is a very important parameter for consideration in food product formulation. Figure 8a and b depicts the variation of

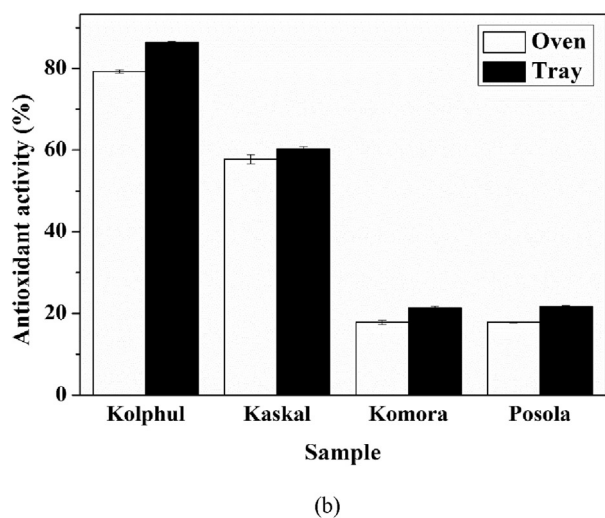
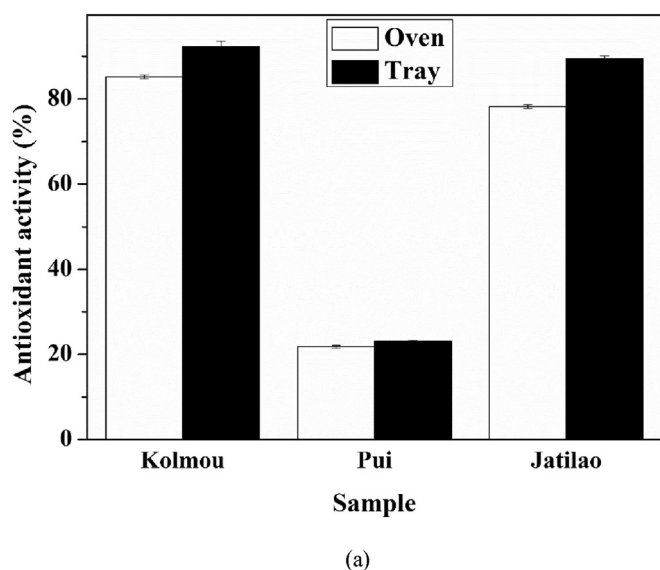


Figure 8. Effect of oven and tray drying on antioxidant activity of (a) leafy and (b) non-leafy vegetables.

antioxidant activity of various vegetables for tray and oven drying. The trends are similar to those reported for vitamin C content. Highest antioxidant activity was evaluated for tray dried Kolmou (92.34%) and Jatilao (89.35%) followed by Kolphul (86.38%). Among all leafy vegetables, Kolmou (92.34% and 85.23% in tray and oven drying) possessed the highest antioxidant activity. Similarly, in non-leafy vegetables, Kolphul (86.38% and 79.26% in tray and oven drying) possessed the highest values. Among all vegetables, Pui (23.08% and 21.81%), Posola (21.68% and 17.80%) and Komora (21.36% and 17.82%), possessed lower antioxidant activity.

The uniform heating coupled with an intermittent circulation of air facilitated better retention of antioxidant activity in tray dried samples. Effective moisture movement within the sample to reach the surface during stagnation period and moisture removal during air circulation period provided better conditions to retain antioxidant activity during tray drying operation. The tray drying operation under intermittent airflow condition enables partial transfer of heat from air to the sample surface to effectively remove moisture but retain heat sensitive nutrients due to intermittency of airflow. The obtained results are best compared to those reported by Saini et al. (2014). Also, it can be noted that Ahluwalia et al. (2012) reported that the tray dried marigold petals possessed higher

antioxidant activity in comparison to vacuum, tray, fan and solar dried samples.

4. Conclusion

For the first time, the comparative nutritional characteristics of tray and oven dried leafy and non-leafy vegetables have been addressed in this work by considering all important parameters. In summary, tray drying provided the best combinations of nutritional parameters in comparison with oven drying. The tray drying process is therefore advantageous for food processing and food product formulations based on NE India's horticultural produce. In general, the tray dried samples possessed higher proximate, vitamin C and antioxidant values. Moisture content, vitamin C and antioxidant activity significantly varied for oven and tray dried samples for each leafy/non-leafy vegetable. In summary, the carried out research is anticipated to serve as an effective guideline to promote food processing in NE India with specific emphasis on ready to eat/cook leafy and non-leafy vegetable soups with optimized nutritional content. This work will be conducted in the near future by our research group after further optimizing tray drying process parameters.

Declarations

Author contribution statement

Imdadul Hoque Mondal: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Latha Rangan: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ramagopal Uppaluri: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

IHM thank MHRD for fellowship. Thanks to Centre for Rural Technology, IIT Guwahati for providing all necessary infrastructural support.

References

- Ahluwalia, P., Kaur, A., Dhillon, G.K., 2012. Effect of different drying methods on chemical and functional properties of marigold petals. *Int. J. Food Nutr. Sci.* 3 (4), 53–59.
- Anjali, K.M., Singh, N., Pal, K., 2012. Effect of sulphur dioxide on plant biochemicals. *Int. J. Pharma Prof. Res.* 3 (2), 538–544.
- AOAC, 2010. *Official Methods of Analysis*, 17 ed. Association of Official Analytical Chemists, Washington, D. C., U.S.A.
- Arinola, S., Ogunbusola, E., Adebayo, S., 2009. Effect of drying methods on the chemical, pasting and functional properties of unripe plantain (*Musa paradisiaca*) flour. *Br. J. Appl. Sci. Technol.* 14 (3), 1–7.
- Barimah, J., Yanney, P., Laryea, D., Quarcoo, C., 2017. Effect of drying methods on phytochemicals, antioxidant activity and total phenolic content of dandelion leaves. *Am. J. Food Nutr.* 5 (4), 136–141.
- Bradford, M.M., 1976. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Anal. Biochem.* 72 (248–254), 248–254.

- Florent Wobiwo, A., Loh Bih, A.M., Thomas Emaga, H., et al., 2015. Nutritive Value of three varieties of banana and plantain blossoms from Cameroon. *Journal of Agricultural Sciences* 5 (2), 52–61.
- Gupta, S., Gowri, B., Lakshmi, A.J., Prakash, J., 2013. Retention of nutrients in green leafy vegetables on dehydration. *J. Food Sci. Technol.* 50 (5), 918–925.
- Joshi, P., Mehta, D., 2010. Effect of dehydration on the nutritive value of drumstick leaves. *J. Metabolomics Syst. Biol.* 1 (1), 5–9.
- Karmakar, K., Muslim, T., Rahman, M.A., 2013. Chemical composition of some leafy vegetables of Bangladesh. *Dhaka Univ. J. Sci.* 61 (2), 199–201.
- Kenghe, R., Jadhav, M., Nimbalkar, C., Kamble, T., 2015. Effect of drying methods on quality characteristics of curry (*Murraya koenigii*) leaves. *Int. J. Environ. Agric. Res.* 1 (5), 8–12.
- Khoozani, A.A., Bekhit, A.E.D.A., Birch, J., 2019. Effects of different drying conditions on the starch content, thermal properties and some of the physicochemical parameters of whole green banana flour. *Int. J. Biol. Macromol.* 130, 938–946.
- Ma, J., Srzednicki, G., Arcot, J., 2016. Effects of drying on stability of nutrients in banana pseudostem in species *Musa balbisiana* and *Musa acuminata*. *J. Food Process. Preserv.* 41 (1), 1–9.
- Okonwu, K., Enyinnaya, A., 2016. Comparative phytochemical studies and proximate analysis of five commonly consumed vegetables of Southern Nigeria. *Asian J. Biol.* 1 (2), 1–7.
- Ravula, S.R., Munagala, S.R., Arepally, D., Reddy, P., 2017. Mathematical modelling and estimation of effective moisture diffusivity, activation energy, energy and exergy analysis of thin layer drying of pineapple. *J. Exp. Biol.* 5 (3), 392–401.
- Sadasivam, S., Manickam, A., 1992. *Biochemical Methods for Agricultural Sciences*. New Age International (P) Limited, Publishers, New Delhi, India.
- Sadasivam, S., Manickam, A., 1992. *Biochemical Method for Agricultural Sciences*. Wiley Eastern Limited and Tamil Nadu Agricultural University Publication, Coimbatore.
- Sahoo, A., Sonkamble, A., Patil, S., 2014. Effect of drying methods on quality of banana powder. *Asian J. Horticulture* 9 (2), 500–502.
- Sakhale K., B., Nandane S., A., Tapre R., A., Ranveer C., R., et al., 2007. Studies on dehydration of curry leaves. *ADIT Journal of Engineering* 4 (1), 62–64.
- Saini, R., Shetty, N., Prakash, M., Giridhar, P., 2014. Effect of dehydration methods on retention of carotenoids, tocopherols, ascorbic acid and antioxidant activity in *Moringa oleifera* leaves and preparation of a RTE product. *J. Food Sci. Technol.* 51 (9), 2176–2182.
- Sana, H., Rani, A.S., Sulakshana, G., 2014. Determination of antioxidant potential in *Spilanthes acmella* using DPPH assay. *Int. J. Curr. Microbiol. Appl. Sci.* 3 (7), 219–223.
- Satter, M.M.A., Khan, M.M.R.L., Jabin, S.A., Abedin, N., Islam, M.F., Shaha, B., 2015. Nutritional quality and safety aspects of wild vegetables consume in Bangladesh. *Asian Pac. J. Trop. Biomed.* 6 (2), 125–131.
- Satwase, A., Pandhre, G., Sirsat, P., Wade, Y., 2013. Studies on drying characteristic and nutritional composition of drumstick leaves by using sun, shadow, cabinet and oven drying methods. *Sci. Rep.* 584 2 (1), 2–4.
- Sochor, J., Zitka, O., Skutkova, H., Pavlik, D., Babula, P., Krska, B., Kizek, R., 2010. Content of phenolic compounds and antioxidant capacity in fruits of apricot genotypes. *Molecules* 15 (9), 6285–6305.
- Tongco, J.V.V., Anis, A.D., Tamayo, J.P., 2015. Nutritional analysis, phytochemical screening, and total phenolic content of *Basella alba* leaves from the Philippines. *Int. J. Pharmacognosy Phytochem. Res.* 7 (5), 1031–1033.