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# Optimizing pre-drying treatments of kale leaves for enhanced processing quality

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**ABSTRACT:** The present research aims to optimize pre-treatments (water blanching, steam blanching) with and without KMS and annealing, and heat moisture treatment (HMT) for drying of kale leaves to minimize deterioration of nutritional and functional constituents and to improve the physico-functional properties of kale powder. ASBK (Annealing-Steam blanching with 0.5% KMS application) was optimized as predrying treatment as it better retained the total antioxidant activity, β-carotene, total phenols, ascorbic acid and anthocyanins. In terms of physico-functional characteristics no significant difference between annealing and HMT was observed ($p$<0.05) but samples differed significantly in properties as compared to control. The optimized pre-drying treatment can be successfully used in processing of kale powder to be used as an ingredient in processed foods. The end product will have improved processing ability and can be used as a fortifying ingredient in processed food industry.

**Key words:** Antioxidant activity, ascorbic acid, anthocyanins steam blanching, β-carotene, total phenols, water blanching

Kale from *Brassica* family is a headless green leafy vegetable and is regarded as one of the most nutrient rich vegetables amongst all. *Brassica* genus contains high levels of available nutrients, anticarcinogenic glucosinolates and beneficial carotenoids (Kopsell *et al*., 2007). It contains the maximum mounts of proteins, vitamins and minerals compared to other brassica crops (Almeida and Rosa, 1996). Green leafy vegetables are rich in dietary carotenoids, and amongst them kale is reported to have highest amounts of lutein and β-carotene concentrations (Mangels *et al*., 1993). They reported total lutein/ zeaxanthin levels in the leaves of kale to be ranged from 147 to 395 μg $g^{-1}$ while levels of β-carotene range from 28 to 145 μg $g^{-1}$ (w.b.). Carotenoids in the human diet, and their consumption is associated with disease reduction (Mortensen *et al.*, 2001). Kale is also rich in phenolic compounds. Heimler *et al*. (2006) compared the main phenolics in several *B. oleracea* crops and reported that broccoli and kale varieties exhibit the highest content of both total phenolics and flavonoids. Plant phenolics also aid in prevention of lifestyle diseases, such as cancer, atherosclerosis and chronic inflammation by inhibiting oxidative degradation and enhancing enzymatic detoxification (Ackland *et al*., 2005; Fresco *et al*., 2010). Due to high moisture content kale cannot be stored for more than a few days at ambient conditions (Korus, 2011). Dehydrated Kale can be used as an ingredient in culinary preparations or can be powdered to be added as a nutrient rich ingredient in processed foods. This requires the dehydrated product to be of good quality with intact nutrients and physicofunctional properties so that it can be incorporated with minimal damage to processed product quality. Drying of vegetables has been practiced for centuries as a preserving technology as dried products can be stored for months without significant nutrient losses (Mwithiga and Olwal, 2005). Drying involves exposure of food material to high temperatures for prolonged periods of time, making these products susceptible to color deterioration (Barreiro *et al*., 1997; Lozano and Ibarz, 1997; Ávila and Silva, 1999; Ibarz *et al*., 1999;) and compromising the flavor, texture, functionality and nutritional contents (Nicoli *et al*., 1991; Deliza *et al*., 2005; Baron *et al*., 2006). Different drying technologies have variable effects on the quality characteristics of the products i.e., detrimental effects of drying can be minimized by using advanced drying technologies but with added cost. Several pretreatments have been used to

minimize the nutritional, sensory and qualitative losses, during and after dehydration and during long-term storage of dehydrated products (Araujo *et al*., 2015). Blanching is the most commonly used methodology to inactivate deteriorative enzymes prior to drying (Di Persioa *et al*., 2007). Conventional blanching utilizes exposure of products to boiling water for a few minutes to inactivate enzymes which may lead to nutritional losses by leaching or non-enzymatic browning in sugar rich fruits (Deliza *et al*., 2005; Baron *et al*., 2006). Steam blanching offers a few advantages in this respect. Potassium metabisulfite (KMS) is also added along with blanching as it provides preserving action and acts as a reducing agent to prevent oxidation during drying. Annealing and HMT (Heat Moisture Treatment) are hydrothermal treatments applied to products to alter their physic-functional properties such as bulk density, water solubility, true density, porosity, wettability in this study effect of drying pretreatments on nutritional, functional and physico-functional properties of kale leaves is evaluated to optimize the best dehydration conditions ensuring maximum retention of nutritional constituents. The developed powder can be used a functional ingredient in processed products such as smoothies, yoghurt, beverage powders etc.

## MATERIALS AND METHODS

### Kale leaves collection and treatments

Vegetable material was obtained from Division of Vegetable Science, Indian Agricultural Research Institute, New Delhi. Red Russian Kale was transported to lab on the day of harvest. The kale leaves were washed and were separated from midrib. The leaves were cut into large squares (6×6 cm). Cut leaves were treated by different pre-drying treatments as per Table 1. Drying was conducted at 50 ºC for approximately 7 h (end point moisture content of 5%). The dehydrated sample was sieved from ASTM mesh 60, packed in PP bags and stored in refrigerated conditions until further analysis.

### Antioxidant activity (%DPPH inhibition)

Methanolic extract of 1 g sample in 20 ml methanol were prepared by keeping them overnight. The samples were centrifuged at 10,000 rpm for 20 min at 4 °C. Antioxidant activity was analyzed by DPPH assay. One ml of extract solution was mixed with 3.9 ml of DPPH (80 µl/ml) and kept in dark for 30 min. Absorbance of reaction mixture was recorded using UV-VIS Spectrophotometer (Spectra Max M2, Molecuar Devices, USA) at 517 nm. Percent change in OD from blank sample was noted as antioxidant activity (%DPPH inhibition).

### Beta-carotene

β-carotene was analysed by the method of Barba, *et al*. (2006) using C-18 Column. Samples were extracted with hexane/acetone/ethanol (50:25:25 v/v/v) followed by evaporation of the hexane layer. The dry extract was dissolved in THF/ACN/methanol (15:30:55 v/v/v) and injected on a C18 column with methanol/ACN (90:10 v/v) + TEA 9 µM as mobile phase (flow rate=0.9 ml/min) and » detection = 475 nm.

### Total phenols

Methanolic extracts as prepared above were used for the analysis. Total phenolic content of the kale powder samples was measured using a modified colorimetric Folin-Ciocalteu method (Singleton and Rossi, 1965). The absorbance was read at 765 nm using UV-VIS spectrophotometer (Spectra Max M2, Molecuar Devices, USA) and total phenols were expressed as mg GAE/100g dry weight.

### Ascorbic acid

Ascorbic acid was determined by titration method using dye 2,6 dicholorophenol indophenol as described in Official Methods of Analysis, AOAC (2000).

### Total anthocyanins

Monomeric anthocyanin content of the kale powder samples was measured using a spectrophotometric pH differential protocol. The sample extracts were mixed thoroughly with 0.025 M potassium chloride pH 1 buffer in 1: 4 ratios of extract to buffer. The absorbance of the mixture was then measured at 510 and 700 nm using a spectrophotometer model (Spectra Max M2, Molecuar Devices, USA). The sample extracts were then combined similarly with

sodium acetate buffer pH 4.5, and the absorbance of these solutions was measured at the same wavelengths. The anthocyanin content in triplicate extracts was expressed as milligrams of cyanidin 3-glucoside equivalents per 100 g using the following formula:

Total anthocyanins (mg/ kg of peel) = A x MW x Dilution x 1000/(ε x W)

where,
A is absorbance = (A 510 - A 700) pH 1.0 - (A 510 - A 700) pH 4.5
MW is molecular weight for cyanidin 3-glucoside = 449.2
ε is the molar absorptivity of cyanidin 3-glucoside = 26900
W is the weight of the sample

**Color**
The color of powdered samples was measured using hunter color lab scan, Virginia USA as L (lightness), a (redness), b (yellowness). The total color change (ΔE) was calculated as (Altan *et al*., 2008).

$$\Delta E = ((L-L_o)^2+ (a-a_o)^2 + (b-b_o)^2)^{1/2}$$

Where subscript 'o' designates color values of the control sample.

**Solubility**
Solubility of kale powder was determined using the procedure developed by Cano-Chauca *et al*. (2005). One gram of the powder (dry basis) was dispersed in 100 ml distilled water by blending at high speed (13,000 rpm) for 5 min using an IKA blender (IKA India Pvt. Ltd., India). The dispersed powder was then centrifuged at 3000 g for 5 min. A 25 ml aliquot of the supernatant was carefully pipetted and transferred to a pre-weighed aluminum dish and then oven-dried at 105 ºC for 5 h. Drying was continued and weighed every hour for 2 h. The solubility of the powder (%) was determined by taking the weight difference

**Bulk density**
The bulk density of the kale powder was measured by the procedure of Goula and Adamopoulus (2008). Pre-weighed sample (5 g) was freely poured into a 25 ml graduated cylinder and the samples were repeatedly tapped manually by lifting and dropping the cylinder under its own weight at a vertical distance of 14 ± 2 mm high until negligible difference in volume between succeeding measurements was observed. The powder bulk density was computed as m/V (kg/m$^3$) where, m is the mass and V is tapped volume of the powder. The measurements were carried out at room temperature in triplicates for each sample.

**Particle density and porosity**
The particle density of sample was calculated by adopting the pycnometer method (Krokida and Maroulis, 1997). Pre-weighed sample (2.5 g) was placed in an empty pycnometer (25 ml), and filled with measured volume of toluene. Porosity was calculated by determining the ratio of bulk density and particle density using the Eqs. (1)–(3):

$$\rho_b = m_s/V_t$$
$$\rho_p = m_s/V_s$$
$$\varepsilon_b = 1-(\rho_b/\rho_p)$$

where, where $\rho_b$ is the bulk density, $\rho_p$ is the particle density, $m_s$ is the mass of mango solids, $V_t$ and $V_s$ is the total and specific volume of the dry solids, respectively.

**Dispersibility**
Dispersibility is the ability of powder to get wetted without formation of dry lumps in water. The International Dairy Federation method of dispersibility measurement specifies a stirring procedure following which the solution is poured through a 210 µm size sieve (Pisecky, 1985).

**Hygroscopicity**
Ten-gram powder bone dried kale powder was placed in an open glass container. Three replicate samples (10g each) for each product were put separately in three sealed humidity jars containing NaCl saturated solution (75.5% humidity) and stored at 25 ºC for 7 days. Samples were prepared at 20 ºC. Hygroscopicity, HG (%) or 1 g of adsorbed moisture

per 100 g dry solids (g/100 g) was calculated using the following equation:

$$HG = (\Delta m/(M+Mi))/(1+\Delta m/M)$$

Where, where Δm (g) is the increase in weight of powder after equilibrium, M is the initial mass of powder and Mi (% wb) is the free water contents of the powder before exposing to the humid air environment (Jaya and Das 2004; Sablani *et al*., 2008; Tonon *et al*., 2008).

**Statistical analysis**

Statistical ranks were obtained by using AGRES data entry module for AGRES statistical software, version 3.01. Each treatment was considered independent of the other and thus, based on factorial ANOVA, one factor analysis was done using completely randomized design model. The ranks obtained for each parameter are marked as superscripts of corresponding values.

## RESULTS AND DISCUSSION

**Antioxidant activity**

Antioxidant activity (%DPPH inhibition) of kale powder prepared by different pre-drying treatments varied from 40.25% (HU) to 55.38% (ASBK) (Table 2). Steam blanching was found to be better than water blanching in terms of antioxidant activity retention owing to leaching losses of antioxidant molecules in blanching water and due to heat damage during blanching and drying operations. Nindo *et al*. (2003) also attributed deterioration of antioxidant activity during drying to heated air that inherently exposes the products to oxidation, thereby reducing total antioxidant activity. Annealing combined with steam blanching demonstrated retention of 98.04% against 73.72% in case of water blanching. Kale powder prepared after blanching along with KMS demonstrated increase in total antioxidant activity. This might be due to KMS itself inhibiting DPPH during antioxidant activity analysis. The highest total antioxidant activity (55.38%) was observed for kale powder prepared by annealing followed by steam blanching with KMS which is 6.19% higher than untreated sample. Araújo *et al.* (2015) also observed similar results during dehydration of Gagela Kale. No significant difference was found in samples prepared by ASBK, HSB and HSBK at 5% level of significance thus justifying steam blanching is better than water blanching as it avoids leaching losses. The results also demonstrate that texturing treatments such as annealing and HMT have no significant effect on antioxidant activity of kale powder.

**β-carotene**

β-carotene content in different samples of kale powder varied from 7.11 to 9.41 µg/g (Table 2). All the drying pre-treatments resulted in loss of β-carotene to variable extents. The highest retention (89.9%) was observed in powder prepared by HMT along with steam blanching with KMS whereas sample prepared by annealing along with water blanching demonstrated least retention of β-carotene (75.55%). Heat and oxidative damage were the primary cause of loss of β-carotene during dehydration. The powders prepared with blanching using KMS demonstrated higher retention due to inherent antioxidant action of KMS that prevented oxidation of β-carotene.

**Total phenols**

Total phenol content of kale powder prepared by different drying pre-treatments in shown in Table 2. Significant degradation of phenols was evident in all the samples of kale powder as compared to control. Maximum total phenols were found in control sample (172.3 mg GAE/g) followed by powder prepared by annealing and steam blanching

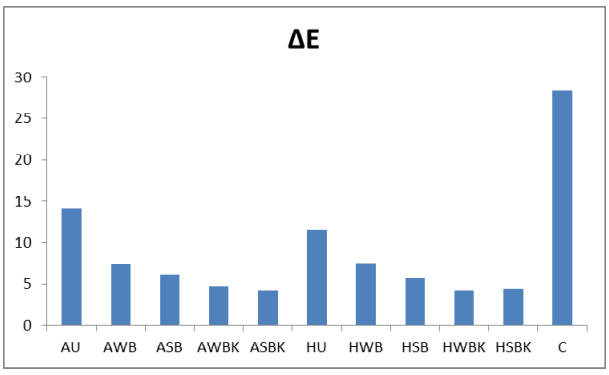


**Fig. 1: Δe values of pre-drying treated kale powders**

(164.2 mg GAE/g). Total phenol degradation during powder preparation can be attributed to leaching losses in water during pretreatments and oxidative damage during dehydration due to high temperature exposure for a prolonged period of time. The difference between treatments was significant ($p$<0.05) as shown in Table 2. Araújo *et al*. (2015) also showed higher total phenolics retention using steam blanching isolated and combined with metabisulfite. These results were in agreement with previous literature (Korus, 2011), that reported polyphenol content decreases by 60% and 49% in non-blanched and blanched kale leaves, respectively.

**Ascorbic acid**

Ascorbic acid content of kale powder decreased in all treatments compared to control (Table 2) with retention ranging from 76.04 to 88.54%. Ascorbic acid content varied from 7.3 to 9.6 mg/g. HSBK and HWB showed highest and lowest ascorbic acid content of 8.5 and 7.3 mg/g, respectively against untreated sample (9.6 mg/g). The difference between control and treated samples and amongst treated samples was significant ($p$<0.05). Water blanching resulted in higher vitamin C degradation, probably due to leaching of this vitamin to the water and also to the thermal degradation inherent to the high temperature employed in the water bath. On the other hand, the samples pretreated with steam blanching exhibited higher vitamin C content than all other pretreatments. Both highest and least retention have been observed with HMT thereby indicating that texturizing pre-treatments were not having any effect on ascorbic acid content. Similar results were obtained in kale by Araújo *et al*. (2015).

**Table 1: Coding of pre-drying treatments given to kale leaves**

| Hydrothermal treatment | Blanching | Treatment code |
|---|---|---|
| Annealing | Unblanch | AU |
| | Water blanching | AWB |
| | Steam blanching | ASB |
| | Water blanching with 0.5% KMS | AWBK |
| | Steam blanching with 0.5% KMS | ASBK |
| HMT | Unblanch | HU |
| | Water blanching | HWB |
| | Steam blanching | HSB |
| | Water blanching with 0.5% KMS | HWBK |
| | Steam blanching with 0.5% KMS | HSBK |
| Control | Unblanch | C |

**Total anthocyanins**

Anthocyanin content of kale powder prepared by different treatments varied from 9.24 (AWB) to 17.43 mg/g (control). Maximum retention was observed in powders prepared by unblanched kale treatments, HU (12.52 mg/g) and AU (11.23 mg/g) amounting to 71.83 and 64.42%, respectively. Significant decrease in anthocyanin content resulted in all the treatments ($p$<0.05). This loss can be attributed to leaching losses during texturizing pretreatments and blanching. Samples blanched with steam demonstrated better retention as compared to water blanched samples owning to less leaching losses in steam. No significant difference was observed between unblanched Annealed and unblanched HMT samples. Thus, justifying hydrothermal treatments used to improve the texture did not have any negative effect on anthocyanin content.

**Color**

Color was analyzed by hunter color lab scan in terms of hue, value and chroma. Change in color of kale powders prepared by different pretreatments was expressed as “E (Fig 1). Least change in color was observed in ASBK (4.2) when compared to color of fresh kale leaf (average of dorsal and ventral surface scores) whereas maximum alteration in color was observed in control sample (28.4) followed by unblanched samples, AU and HU with “E values of 14.2 and 11.6, respectively.

**Solubility**

Solubility of kale powder is an important parameter considering the end use of powder as an ingredient in processed foods. Solubility of kale powder samples made by different pretreatments varied from 57.6 (Control) to 61.8% (HU). Solubility increased in all the treatments with HMT processed kale powders demonstrating higher solubility compared to annealing treatment (Table 3). This parameter is attained after the powder undergoes dissolution steps of sinkability, dispersability and wettability (Chen and Patel, 2008). Thus, improvement in solubility

**Table 2: Antioxidant components of dehydrated kale powder prepared by various pre-treatments**

| Treatment | Antioxidant activity (%DPPH inhibition) | β-carotene (µg/g) | Total phenols (mg GAE/g) | Ascorbic acid (mg/g) | Anthocyanins (mg/g) |
|---|---|---|---|---|---|
| AU | 47.56$^{c}$ (±0.99) | 8.32$^{b}$ (±0.06) | 158.2$^{c}$ (±0.41) | 8.2$^{bc}$ (±0.13) | 11.23$^{bcd}$ (±0.14) |
| AWB | 38.45$^{e}$ (±0.84) | 7.11$^{c}$ (±0.11) | 148.4$^{e}$ (±0.38) | 7.7$^{cd}$ (±0.12) | 9.24$^{d}$ (±0.11) |
| ASB | 51.13$^{b}$ (±0.81) | 8.14$^{bc}$ (±0.09) | 164.2$^{bc}$ (±0.37) | 8.1$^{bc}$ (±0.09) | 10.53$^{cd}$ (±0.17) |
| AWBK | 44.35$^{cd}$ (±0.92) | 7.92$^{d}$ (±0.08) | 149.4$^{e}$ (±0.45) | 7.9$^{c}$ (±0.07) | 9.54$^{d}$ (±0.12) |
| ASBK | 55.38$^{a}$ (±0.76) | 8.46$^{b}$ (±0.17) | 163.6$^{bc}$ (±0.42) | 8.3$^{bc}$ (±0.11) | 9.52$^{d}$ (±0.08) |
| HU | 48.67$^{c}$ (±0.71) | 7.98$^{c}$ (±0.11) | 156.4$^{c}$ (±0.44) | 7.9$^{c}$ (±0.11) | 12.52$^{bc}$ (±0.08) |
| HWB | 40.25$^{d}$ (±0.91) | 7.93$^{c}$ (±0.13) | 151.2$^{d}$ (±0.32) | 7.3$^{d}$ (±0.14) | 9.52$^{d}$ (±0.11) |
| HSB | 52.54$^{ab}$ (±0.98) | 8.36$^{b}$ (±0.07) | 158.3$^{c}$ (±0.36) | 7.8$^{c}$ (±0.08) | 10.45$^{cd}$ (±0.09) |
| HWBK | 42.14$^{d}$ (±0.64) | 8.12$^{bc}$ (±0.09) | 153.1$^{d}$ (±0.49) | 7.7$^{cd}$ (±0.11) | 9.78$^{d}$ (±0.07) |
| HSBK | 53.21$^{ab}$ (±0.78) | 8.46$^{b}$ (±0.11) | 151.3$^{d}$ (±0.29) | 8.5$^{b}$ (±0.14) | 9.58$^{d}$ (±0.14) |
| C | 52.15$^{ab}$ (±0.77) | 9.41$^{a}$ (±0.12) | 172.3$^{a}$ (±0.33) | 9.6$^{a}$ (±0.13) | 17.43$^{a}$ (±0.12) |

Each value is an average of ten observations.
Different alphabets represent statistically different values at 5% α; values in parenthesis represent standard deviation.

**Table 3: Physico-functional properties of dehydrated kale powder prepared by various pre-treatments**

| Treatment | Solubility (%) | Bulk density (g/cm$^3$) | Particle density (g/cm$^3$) | Porosity | Hygroscopicity (%) |
|---|---|---|---|---|---|
| AU | 59.3$^{ab}$ (±1.21) | 0.673$^{a}$ (±0.85) | 1.828$^{ab}$ (±0.013) | 0.631$^{a}$ (±0.014) | 0.682$^{ab}$ (±0.018) |
| AWB | 58.3$^{bc}$ (±1.26) | 0.681$^{a}$ (±0.87) | 1.825$^{ab}$ (±0.012) | 0.626$^{a}$ (±0.012) | 0.674$^{ab}$ (±0.014) |
| ASB | 58.4$^{bc}$ (±1.14) | 0.678$^{a}$ (±0.62) | 1.829$^{ab}$ (±0.017) | 0.629$^{a}$ (±0.008) | 0.681$^{ab}$ (±0.015) |
| AWBK | 58.2$^{bc}$ (±1.09) | 0.685$^{a}$ (±0.74) | 1.829$^{ab}$ (±0.008) | 0.625$^{a}$ (±0.006) | 0.654$^{ab}$ (±0.013) |
| ASBK | 58.6$^{ab}$ (±0.98) | 0.682$^{a}$ (±0.81) | 1.826$^{ab}$ (±0.012) | 0.626$^{a}$ (±0.011) | 0.663$^{ab}$ (±0.021) |
| HU | 61.8$^{a}$ (±1.13) | 0.628$^{ab}$ (±0.71) | 1.814$^{a}$ (±0.014) | 0.653$^{a}$ (±0.013) | 0.791$^{a}$ (±0.014) |
| HWB | 61.2$^{a}$ (±1.28) | 0.614$^{b}$ (±0.73) | 1.817$^{a}$ (±0.013) | 0.661$^{a}$ (±0.014) | 0.784$^{a}$ (±0.008) |
| HSB | 58.4$^{bc}$ (±1.21) | 0.678$^{ab}$ (±0.81) | 1.829$^{ab}$ (±0.012) | 0.629$^{a}$ (±0.008) | 0.781$^{a}$ (±0.017) |
| HWBK | 60.9$^{a}$ (±0.95) | 0.617$^{b}$ (±0.69) | 1.814$^{a}$ (±0.009) | 0.659$^{a}$ (±0.012) | 0.762$^{a}$ (±0.015) |
| HSBK | 61.4$^{a}$ (±1.04) | 0.611$^{b}$ (±0.78) | 1.811$^{a}$ (±0.018) | 0.662$^{a}$ (±0.014) | 0.751$^{a}$ (±0.018) |
| C | 57.6$^{d}$ (±1.13) | 0.517$^{c}$ (±0.77) | 1.842$^{c}$ (±0.014) | 0.719$^{b}$ (±0.006) | 0.521$^{c}$ (±0.017) |

Each value is an average of ten observations.
Different alphabets represent statistically different values at 5% α; values in parenthesis represent standard deviation.

enhances the processing ability of kale powder for it to be an ingredient in processed foods. There was no significant difference between treatments in regard to blanching conditions ($p<0.05$). Significant difference ($p<0.05$) was observed between annealing, HMT and control samples with solubility decreasing in order as HMT, annealing and control. The higher solubility of pre-treated samples could be attributed to a higher degree of macromolecular disorganization of the material during hydrothermal conditioning.

**Bulk density**

For all the pre-treatments bulk density increased significantly. The increase in annealed samples was found to be higher than HMT. Bulk density of kale powder prepared by different pretreatments ranged from 0.517 g/cm$^3$ (control) to 0.685 g/cm$^3$ (AWBK). No significant difference ($p<0.05$) was found within different annealed and HMT samples indicating that variation in type of blanching does not affect bulk density. The effect of HMT and annealing on bulk density was significant. These results may be attributed to the decrease in the inter-particle voids of particles with larger contact surface areas per unit volume. Similar observation was reported for bulk density of ginger powder at different particle sizes (Xiaoyan, 2008). Also, the high temperature used in drying may have led to development of compact structure with high bulk density.

**Particle density and porosity**

No significant difference between particle density of different kale powder samples was observed

($p$<0.05). Particle density varied from 1.811 to 1.842 g/cm$^3$ (Table 3). Porosity ranged from 0.625 (AWBK) to 0.719 (control). Porosity decreased for all the samples of kale powder with no significant difference between treatments but it differed significantly against control ($p$<0.05). Decrease in porosity can be attributed to increase in bulk density due to increased compactness of particles after HMT and annealing treatments. Barbosa-Canovas *et al.* (2005) were also consistent with the explanation that powder characteristics such as particle size may result in significant changes in bulk density and porosity.

**Hygroscopicity**

Demarcation values for hygroscopicity (HG) of kale powder ranging from 5.13% to 9.38% were considered as the basis for comparing the results in this study (Jaya and Das, 2004). Hygroscopicity of kale powder samples ranged from 0.521 (control) to 0.791 (HU) (Table 3). Thus, kale powder samples were non-hygroscopic, even for the lower range hygroscopicity of 5.13%. The increase in hygroscopicity was not significant statistically ($p$<0.05) amongst different treatments but was different against control. The low hygroscopicity can be attributed to lack of inherent hygroscopic macro components in kale.

## CONCLUSION

The nutritional and physico-functional properties of kale powder were affected significantly by drying pretreatments. Drying of kale leaves after application of individual or combination pretreatments was carried out at 50 ºC to achieve a final moisture content of 0.05 kg/kg of dry kale powder. It was observed that antioxidant parameters were affected more by blanching treatments whereas physico-functional properties were affected more by HMT and Annealing treatments. Steam blanching offered better retention of antioxidant components with ASBK application showing retention of total antioxidant activity, β-carotene, total phenols, ascorbic acid and anthocyanins to be 93.8, 79.27, 94.95, 86.45 and 54.61% respectively. ASBK also demonstrated least change in color compared to fresh green kale leaf. Annealing and HMT both significantly improved physico-functional properties of kale powder such a solubility, bulk density, porosity etc. but no significant difference was identified between annealed and HMT sample. Overall, our study concludes that annealing followed by steam blanching with KMS (ASBK) as a pre-drying treatment yield the best quality kale powder. The study provides an opportunity to the powder processing industry in selecting better drying pretreatments that can be utilized for the manufacture of high-quality kale powder for end uses in processed foods such as noodles, pasta, bread etc. Further research should be done for developing a chemical free approach for functionalizing dehydrated kale powder.

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