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Grinding characteristics of coriander, fenugreek and black pepper under cryogenic and ambient grinding conditions

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Abstract

In present communication, grinding characteristics coriander (*cv.* RCr-41), fenugreek (cv. AM-1**)** and black pepper (cv. Panniyar–1) were investigated under ambient and cryogenic grinding conditions. The average particle size volume surface mean diameter, mass mean diameter, volume mean diameter and specific surface of mixture of ambient ground spices were found higher than that of cryogenic ground spices. The average particle size of ground coriander, fenugreek and black pepper were 0.492 mm, 0.243 mm, 0.299 mm (cryogenic condition) and 0.843 mm, 0.430 mm, 0.408 mm (ambient condition), respectively. The energy constants and specific energy consumption under cryogenic grinding were lower than that of under ambient grinding conditions for all studied spices. For black pepper energy values i.e Rittinger's constant and Kick's constant were found as 23.5 and 27.2, and 90.8 and 84.6 for cryogenic and ambient grinding conditions, respectively. This investigation recommends that grinding characteristics of coriander, fenugreek and black pepper under cryogenic grinding condition was better than that of ambient grinding condition.

Key words : Coriander, Fenugreek, Black pepper, grinding characteristics, cryogenic grinding, Colour.

Introduction

Coriander (*Coriandrum sativum*) is an annual herb in the family *Apiaceae* and native to southern Europe and North Africa to Southwestern Asia. It has been used as a folk medicine for the relief of anxiety and insomnia in Iran. The seeds of coriander are almost ovate globular and there are many longitudinal ridges on its surface. The length of the seed is 3–5 mm and colour, when dried, is usually brown, but also may be green, straw-colored or off white. Fenugreek (*Trigonella foenumgraecum*) is an annual herb that belongs to the family *leguminosae*, widely grown in India, Pakistan, Egypt, and Middle Eastern countries. India is the largest producer of fenugreek in the World (Edison, 9). In India, Rajasthan, Gujarat, Uttaranchal, Uttar Pradesh, Madhya Pradesh, Maharashtra, Haryana and Punjab are the major fenugreek producing states. Rajasthan has maximum area and production of about more than 80% of India's total production. Due to its strong flavour and aroma fenugreek leaves and seeds are widely consumed in Indo-Pak subcontinent as well as in other oriental countries as a spice in food preparations, and as an ingredient in traditional medicine. It is rich source of calcium, iron, carotene and other vitamins (Sharma *et al.*,17). Black pepper (*Piper nigrum* L.) is one of the most important spices and its fruits, known as berries, are dark green in colour which becomes bright orange and red when ripe. After sun drying, its colour changes from grayish to dark brown. These are small dark brown or nearly black spherical fruits with a more or less regular and deep reticulate, wrinkled surface. It is consumed in the form of whole, cracked, coarse or medium or fine powder and oleoresin.

Grinding of spices is an age-old practice like grinding of other food materials. It is an important unit operation to increase the surface area of ground spice and therefore availability of oil content and flavouring components.. Various factors affect the power consumption in grinding operation e.g. structure of the material, grinding mechanism and operating parameters (Das, 2). Grinding is one of the most power consuming unit operations in which almost 99% of input energy is converted into heat due to friction whereas 1% is utilized for breaking the bond between particles. In conventional or ambient grinding of spices, temperature rises to the extent of 43-95^{0}C (Singh and Goswami, 9) which causes the oil release and loss of aromatic and medicinal properties of spices. It makes ground product gummy, sticky and results in chocking of sieves (Singh and Goswami, 9). Temperature

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rise of the ground product is a major concern of the conventional grinding process and therefore it is necessary to perform the grinding under lower temperature conditions.

Cryogenic grinding of spices has been scientifically proved to as a suitable technique with less loss of volatile oil content and improved colour of the product. The flavour, colour and nutritional values of the product were found better in cryogenic grinding as compared to ambient grinding (Shimo *et al*., 8: Saxena et. al., 2013). The extremely low temperature in the grinder solidifies the oil of spices and hence become brittle. The brittle spices crumble easily, permitting grinding to a finer and more consistent size (Stepien, 12). Limited research information is available on grinding characteristics of spices particularly under cryogenic grinding conditions. In present study, grinding characteristics and colour attributes of coriander, fenugreek and black pepper were studied to investigate the influence of cryogenic and ambient grinding conditions.

Materials and methods

Sample preparation

Coriander (cv. RCr-41) and fenugreek (cv. AM-1**)** were provided from National Research Centre of Seed Spices (NRCSS), Ajmer, Rajasthan, India while black pepper (cv. Panniyar–1) was obtained from Indian Institute of Spices Research (IISR), Kozhikode, Kerala, India. The spices were cleaned manually by removing adhered foreign matter and immature seeds, if any. The initial moisture content of the coriander, fenugreek and black pepper seeds were determined (AOAC, 1) and found to be 12.1, 8.1 and 7.8 % w. b., respectively. The spice seeds of 400 g each samples at its initial moisture content were used for experimental purpose.

Experimentation

The experiments were conducted at Central Institute of Post Harvest Engineering and Technology (CIPHET) Ludhiana, Punjab, India. A laboratory grinder with pin mill set up (M/s Hosakowa Alpine, Germany, Model: 100UPZ, three-phase motor, 3 HP, 3000 rpm) was utilized for the grinding of spices under cryogenic and ambient conditions. For cryogenic grinding condition, liquid nitrogen (LN_2) was supplied at the entry of feed screw conveyor in the pre-cooler to bring the feed material to low temperature (-50 ºC or lower). Feed material from pre-cooler enters at the centre of the pin mill through feed chute of feed hopper. Grinding of spice was performed (feed screw speed: 4 rpm, and pin mill speed: 10000 rpm) and the final ground product was collected at pin mill outlet. Control panel was used to record the various parameters such as feed screw speed (rpm), electric current (A) and pin mill speed (rpm). The grinder was run at no-load condition and value of electric current was recorded from the control panel. The value of electric current was also recorded at on load condition i.e. during the grinding of sample.

Theoretical considerations

The average size of seed, in terms of geometric mean diameter, was determined by measuring the three linear dimensions viz., length (L), width (W) and thickness (T) of randomly picked spice seeds and using following expression (Sahay and Singh, 7).

$$\text{Geometric mean diameter} = \sqrt[3]{L \times W \times T}$$

Sphericity (Φ) is defined as the ratio of geometric mean diameter (GMD) to the major intercept. It was calculated using following expression

$$\text{Sphericity, } \Phi = \frac{(L \times W \times T)^{\frac{1}{3}}}{L}$$

Sieve analysis of ground spices were carried out (Sahay and Singh, 7), to determine the fineness modulus. Fineness modulus is calculated by adding the total percentages of a sample of the aggregate retained on each of a specified series of sieves and dividing by 100.

$$FM = \frac{Total\ \ percent\ retained\ on\ sieve}{100}$$

Using value of FM, the Average Particle Size (D_p) was calculated using following equation

$$D_p = \left[0.135 \times \left(1.366\ \right)^{FM}\ \right] \quad (1)$$

True density (ρ_t) was determined by using gas (nitrogen) pycnometer (make IQI, USA, Model2: *Hymipyc*). The pycnometer was calibrated using calibration kit and standard volume of steel ball having 1.0725 cc and after this; the weighed samples were used in sample chamber of the pycnometer for determination of true density.

The various grinding characteristics were evaluated using following expressions (Sahay and Singh, 7)

$$\text{Volume surface mean diameter, } D_{VS} = \frac{1}{\sum_{i=1}^{n}\left(\frac{m_i}{D_{pi}}\right)} \quad (2)$$

Where, m_i and Dpi are mass retained and mean diameter in each increment, respectively

$$\text{Mass mean diameter, } D_m = \sum_{i=1}^{n}\left(m_i D_{pi}\right) \quad (3)$$

$$\text{Volume mean diameter, } Dv = \left[\frac{1}{\sum_{i=1}^{n}\left(\frac{m_i}{D_{Pi}^3}\right)}\right]^{\frac{1}{3}} \quad (4)$$

Rittinger's constant (C) was determined using Rittinger's law which states that the work in crushing is proportional to the new surface created.

$$E = C\left[\frac{1}{x_p} - \frac{1}{x_f}\right] \quad (5)$$

where, x_f and x_p are the diameter of feed and product, respectively. E is the amount of work required to reduce a unit mass of feed from x_f to x_p and C is Rittenger's constant.

Kick's constant (C_K) was determined using Kick's law which states that energy required to reduce a material in size is directly proportional to the logarithmic size reduction ratio.

$$E = C_K \ln\left(x_p / x_f\right) \quad (6)$$

where, C_k is Kick's constant and x_p and x_f are the size of product and feed, respectively.

The colour of ground spices (spice powder) were measured using Hunter Lab labScan XE (Hunter Associates laboratory Inc., Reston, Virginia, USA) in terms of lightness (L), redness (a) and yellowness (b). The hue angle (h^0) and croma (C) were computed using following equations (Mridula *et al*., 5):

$$h^0 = \tan^{-1}(b/a) \quad (7)$$

and

$$C = \sqrt{\left(a^2 + b^2\right)} \quad (8)$$

Specific surface of mixture (Ass) was determined using following expression:

$$Ass = \left[\frac{1}{(D_{VS}\Phi)_t / 6}\right] \quad (9)$$

Where Φ, sphericity of seed

Weight of one particle = $(4/3)\pi(D_m/2)^3\rho_t$

Where, ρ_t and D_m are true density and mass mean diameter of ground product, respectively.

$$\text{Number of particles} = \frac{\text{Weight of one seed}}{\text{Weight of one ground pareticle}} \quad (10)$$

The feed rate (f) was calculated as a ratio of weight of the feed (M_s) to time consumed during the operation of grinder (t).

$$\text{Feed rate (f), kg/h} = \frac{M_s}{t}$$

Energy consumption during grinding operation (ΔW) was calculated by following expression

$$\Delta W = W_{OL} - W_{NL} = V \times (I_{OL} - I_{NL})$$

Where, V is operational voltage of operation and I_{OL} and I_{NL} are the current recorded at on load and no load conditions, respectively.

Specific energy consumption (ΔE) was determined by using the following equation

$$\Delta E = \frac{\Delta W \times 3.6}{f} \quad (11)$$

Results and Discussion

Figure 1 presents the grinding characteristics of coriander, fenugreek and black pepper. For ground coriander, the average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found as 0.492 and 0.843 mm, 0.360 and 0.623 mm, 0.393 and 0.713 mm, and 0.323 and 0.523 mm for cryogenic and ambient grinding conditions, respectively (Figure 1a). The average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found as 0.243 and 0.430 mm, 0.308 and 0.388 mm, 0.194 and 0.382 mm, and 0.231 and 0.301 mm, for cryogenic and ambient grinding conditions, respectively for ground fenugreek (Figure 1b). For ground black pepper, the average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found as 0.299 and 0.408 mm, 0.326 and 0.369 mm, 0.263 and 0.410 mm, and 0.252 and 0.286 mm for cryogenic and ambient grinding conditions, respectively (Figure 1c). It was observed that the average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found lower in cryogenic grinding as compared to ambient grinding (Meghwal and Goswami, 4; Singh and Goswami, 9; Murthy and Bhattacharya, 6). It may be due to fine powder obtained in cryogenic grinding due to brittleness of the feed material under cryogenic conditions.

Figure 2 shows the energy values of coriander, fenugreek and black pepper. For coriander sample, energy values i.e Rittinger's constant and Kick's constant were found as 30.1 and 27.2, and 67.5 and 43.4 for cryogenic and ambient grinding conditions, respectively (Figure 2a). The energy values i.e Rittinger's constant and Kick's constant were found as 3.8 and 6.1, and 18.3 and 19.8 for cryogenic and ambient grinding conditions, respectively (Figure 2b) for fenugreek sample. For black pepper sample, energy values i.e Rittinger's constant and Kick's constant were found as 23.5 and 27.2, and 90.8 and 84.6 for cryogenic and ambient grinding conditions, respectively (Figure 2c). The value of energy constants i.e. Rittinger's constant and Kick's constant found lower in cryogenic grinding in comparison to ambient grinding.

The colour values of ground coriander and ground fenugreek are presented in Figure 3. For ground coriander,

colour values such as *L, a, b*, hue angle and chroma were found 51.1 and 46.6, 5.1 and 9.2, 53.8 and 51.4, 85.1° and 80.1°, and 61.3 and 52.6 for cryogenic and ambient grinding conditions, respectively (Figure 3a). The colour values e.g. *L, a, b,* hue angle and chroma were found as 77.8 and 69.9, 3.8 and 4.6, 28.2 and 38.4, 82.5° and 82,6°, and 27.7 and 38.9 for cryogenic and ambient grinding conditions, respectively (Figure 3b) for ground fenugreek. For ground black pepper, colour values such as *L, a, b*, hue angle and chroma were found 33.4 and 35.2, 8.6 and 6.6, 29.7 and 24.1, 73.1° and 74.2°, and 46.7 and 42.4 for cryogenic and ambient grinding conditions, respectively (Figure 3c). The cryogenically ground samples are better in colour.

The values of specific surface of mixture, number of particles/g and specific energy consumption for coriander, fenugreek and black pepper under cryogenic and ambient conditions are presented in Table 1. For coriander, fenugreek and black pepper, the values of specific surface of mixture and number of particles/g were higher in cryogenic grinding conditions in comparison to ambient grinding conditions. The specific energy consumption for coriander, fenugreek and black pepper was lower in cryogenic grinding conditions in comparison to ambient grinding conditions as expected by Meghwal and Goswami, 4).

Conclusion

From present investigation on coriander, fenugreek and black pepper, some grinding characteristics such as the average particle size, volume surface mean diameter, mass mean diameter and volume mean diameter were found lower in cryogenic grinding as compared to ambient grinding. The energy values i.e Rittinger's constant and Kick's constant were found as 3.8 and 6.1, and 18.3 and 19.8 for cryogenic and ambient grinding conditions, respectively for fenugreek sample. It was also observed that for cryogenic grinding in comparison to ambient grinding, less specific energy consumption was found.

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Table 1. Some grinding parameters of studied spices under different grinding conditions

Spice	Grinding condition	Seed geometric mean diameter, mm	Specific surface of mixture, mm^2/g	Number of particles/g	Specific energy consumption, kWh/tonne
Coriander	Ambient	3.36	10251	3393	60.00
	Cryogenic	3.36	18081	17397	52.22
Fenugreek	Ambient	2.53	17857	27661	35.36
	Cryogenic	2.53	22503	153752	14.43
Black Pepper	Ambient	4.45	23544	40617	202.17
	Cryogenic	4.45	28971	102721	73.33

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Figure 1. Grinding characteristics under ambient and cryogenic grinding conditions (a) coriander (b) fenugreek and (c) black pepper

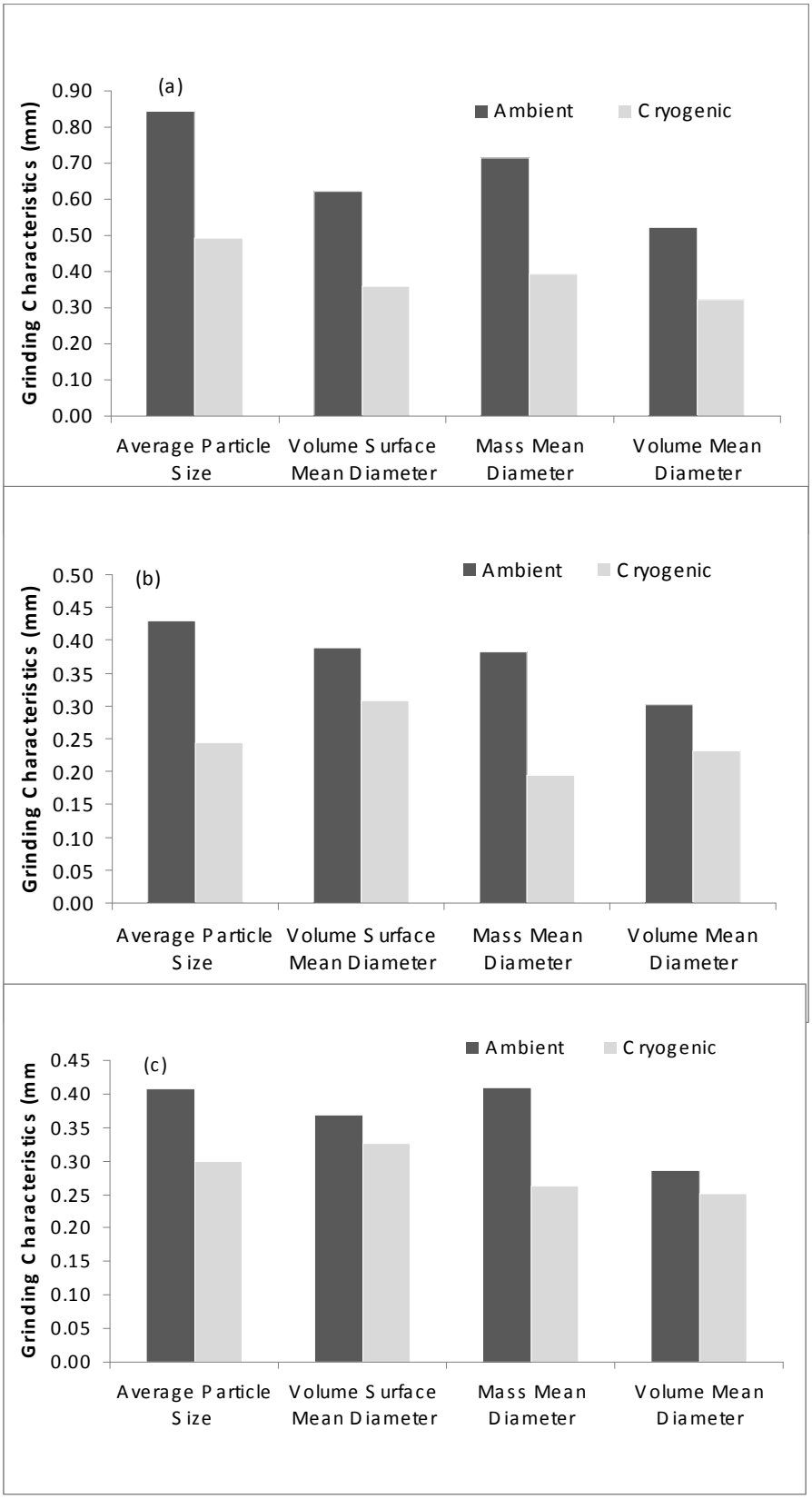
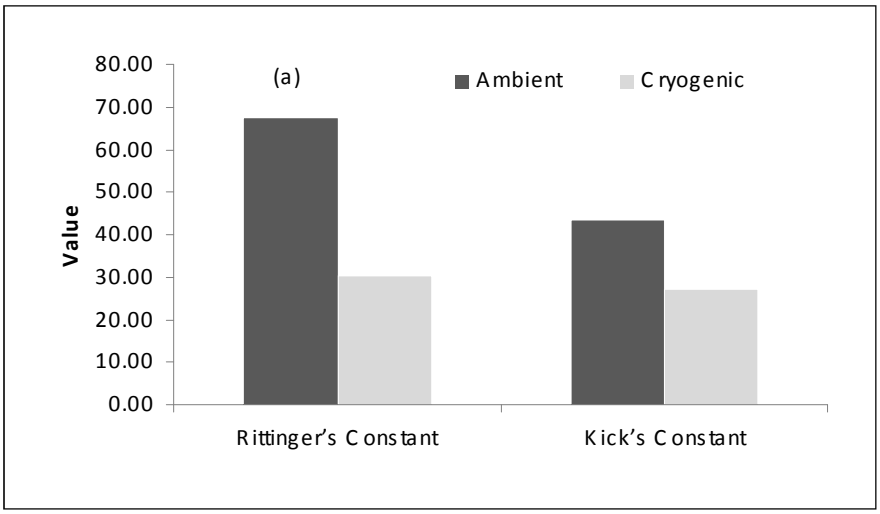
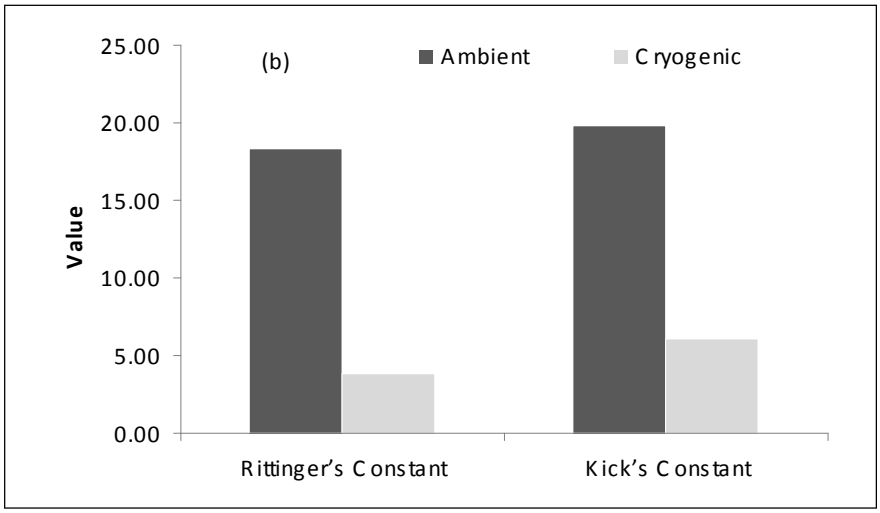


Figure 2. Energy constants under ambient and cryogenic grinding conditions (a) coriander (b) fenugreek and (c) black pepper





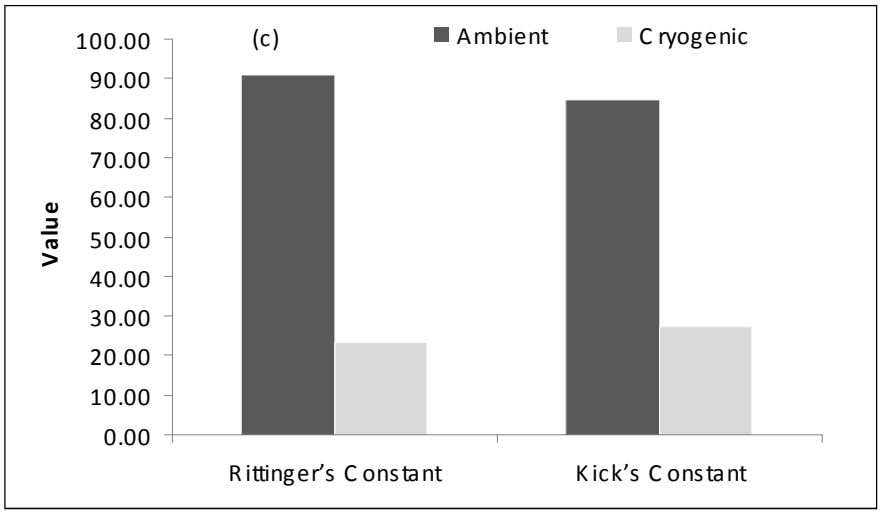
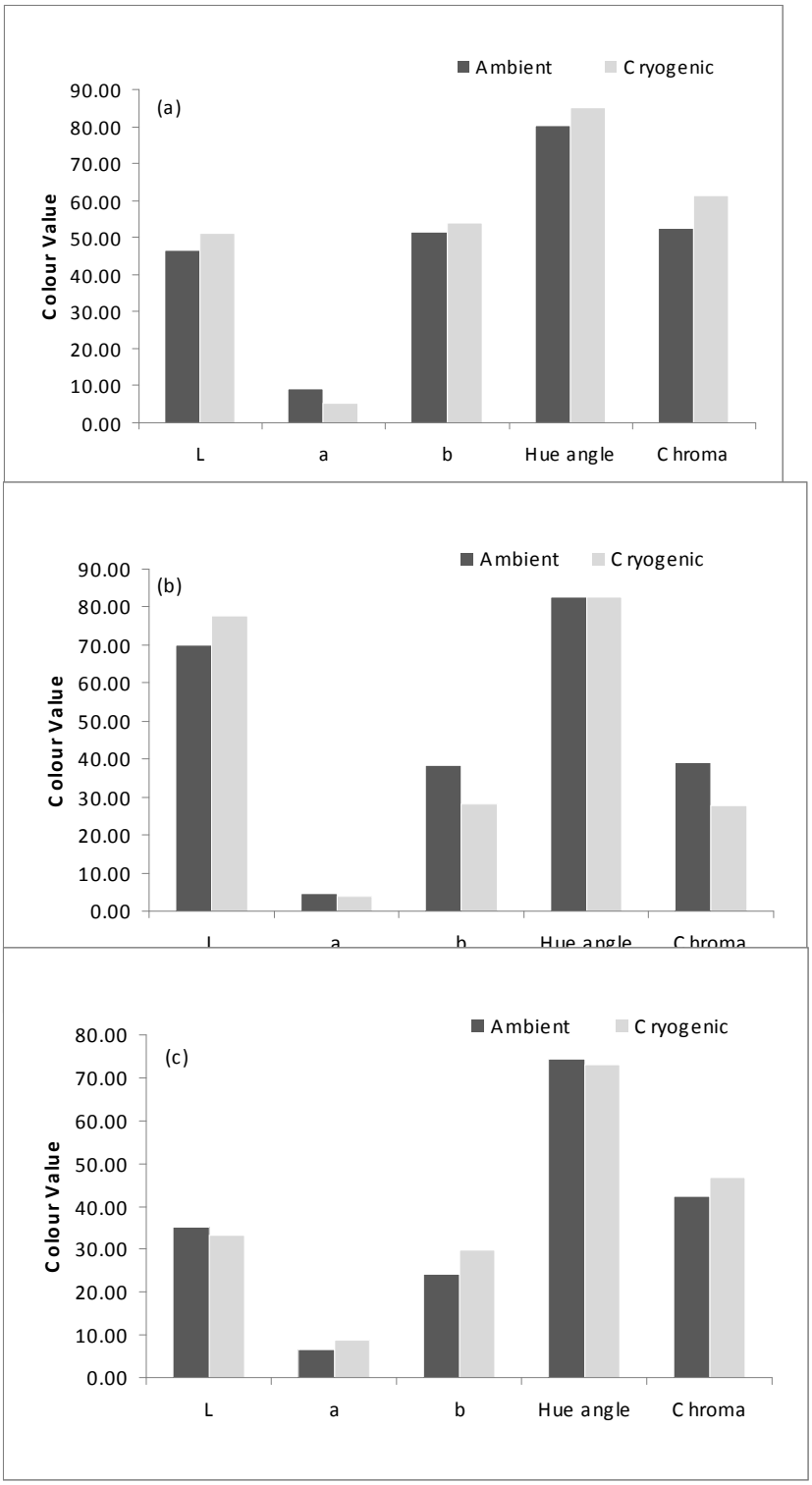


Figure 3. Colour attributes of ground spices under ambient and cryogenic grinding conditions (a) coriander (b) fenugreek and (c) black pepper



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