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Performance Evaluation of a Dehumidifier Assisted Low Temperature Based Food Drying System

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Abstract: *Low-temperature drying allows foods such as green leafy vegetables to be dried without losing the original color and texture. The system proposed in this paper consists of desiccant dehumidifier which removes the moisture from the air and increases its adsorption capacity. Airflow rate and regeneration temperature of the dehumidifier was controlled to ensure minimal damage to the food during the drying process in comparison with tray drying. Fenugreek green leaves were dried from an initial moisture content of 88.6 % to 5% (wb). The fenugreek dried with rotary desiccant bed dehumidifier has superior green color, flavour and maximum retention of various nutrients.*
Keywords: *Adsorption Capacity, Desiccant Dehumidifier, Fenugreek Green leaves, Flavour and Nutrients*

I. Introduction

Green leafy vegetables are a group of edible leaves that are rich in nutrients such as vitamins and minerals. Some of the vegetables, which fall in this group, are spinach, fenugreek leaves, mustard leaves, mint, and coriander. Fenugreek (methi) is very popular leafy vegetable in India. Fenugreek is mostly used in Northern India as a spice, especially for pickles. Its leaves are used in making poultice for external and internal swellings. Dry leaves are used for flavoring and seasoning also. Leaves are rich in protein, iron and vitamin A. [1]. It provides natural food fibre and other nutrients required in human body [2]. The moisture content in fresh agricultural produce is the basic cause for spoilage. The removal of moisture from foods retards many of the moisture-mediated deteriorative reactions and prevents the growth and reproduction of microorganisms [3]. If water is removed then the shelf life of agricultural produce can be increased. Removal of water also reduces the cost of storage and transportation by reducing both weight and volume of final product. The quality of dehydrated food product is influenced by drying conditions such as temperature, airflow rate, and relative humidity [4]. Now a day's various type of drying technologies are used for drying each one having its characteristic advantages and disadvantages. Sun drying is traditional method of preservation of fenugreek. But sun dried product is of poor quality especially with regards to color and flavor due to direct exposure to sun as often practiced [5]. Also, sun drying is not hygienic, does not have a control over drying and is not dependable throughout the year. Low Humidity Air (LHA) dried fenugreek had superior green color and a more porous and uniform structure than those obtained from Radiofrequency (RF) and Hot air (HA) drying. Dehydrated fenugreek green leaves showed good consumer acceptance as well as shelf life [6]. Some of the foods and other agricultural products such as spices, green leafy vegetables and herbs are heat sensitive, it is desirable to process low temperatures. Fenugreek (methi) is one of the well-known spices in human food. Fenugreek has strong spicy and seasoning type sweet flavor [7]. Low-temperature desiccant based drying allows foods such as vegetables to be dried without losing the original color and texture. The system consists of an airflow control system to improve drying rate and temperature control to ensure minimal damage to the food during the drying process in comparison with tray drying. Through, the experimental evaluation of the system, it is demonstrated that dried vegetables produced by this method retain their fresh color and high vitamin content [8]. However, the use of heat to evaporate moisture from the food also results in a loss of fresh color, vitamins and texture. The fresh color of food can be maintained if drying can be performed at low temperature, which can be achieved through the use of a desiccant [9]. Once the solid desiccants become saturated, they can be regenerated and used again [10]. In drying, desiccant is used to lower the air humidity and produce optimum air conditions required for drying irrespective of the ambient air conditions.

In order to improve the drying rate of fenugreek leaves under low-temperature conditions, the driving force for mass transfer can be enhanced by several strategies. Reducing the relative humidity of hot air is one such approach, which increases the moisture-absorbing capacity of drying air. This helps in maintaining higher driving force for mass transfer between inner layers and the material surface. The desiccant based drying system can be used for drying of fenugreek leaves and reduce drying time and improve quality of the dried product. So, to solve the problem of uncontrolled drying temperature and unfavourable climatic conditions there is a need to develop a desiccant based food drying system in which a dehumidifier is used to absorb the moisture from air and with the help of heater, air is dried to desirable relative humidity and temperature and passed through food kept in drying chamber. Temperature of drying air and airflow rate are crucial parameters for increasing the drying rate and dried food quality and hence needs to be optimized for drying of fenugreek green leaves in a desiccant based food drying system.

II. Material And Methods

2.1 Material

Fresh fenugreek (*Trigonella foenum-graecum*) green (average thickness 0.7 mm) was procured from a local market. The roots as well as extraneous foreign material were removed and the greens were washed in water to remove dirt and soil. Fenugreek green (2 kg) were used for each experiment and a single layer of the material was spread on five trays in the dryer. The fenugreek dried on low temperature of 45°C, keeping in view the product quality as well as time required for drying by maintaining air mass flow rate in the desiccant dehumidifier. For comparison of drying time and quality of dried product samples were also dried in tray dryer at same temperature.

2.2 Desiccant Dehumidifier

The schematic of the desiccant dehumidifier is shown in Figure 1 is a device that removes moisture from air but do so without cooling the air below its dew point. In case of a desiccant dehumidifier, water vapor from a process stream of moist air adsorbs onto the surface of a desiccant material. Eventually, the desiccant material becomes saturated with water and must be regenerated through a drying process. In desiccant dehumidifier, the process and regeneration air streams operate at the same time and a wheel of desiccant material rotates between the streams. At any given time, a portion of the desiccant is being regenerated while the remainder is adsorbing water from the process stream. The regeneration air comes from the same source as the process air and is heated to lower its relative humidity. The process air enters the dehumidifier at a certain state (usually relatively cool and moist). As water adsorbs onto the desiccant, it gives up its heat of sorption, warming the surrounding air.

The process air leaves the dehumidifier drier and warmer than it entered. Desiccant dehumidifiers are quite different from cooling-based dehumidifiers. Instead of cooling the air to condense its moisture, desiccants attract moisture from the air by creating an area of low vapor pressure at the surface of the desiccant. The pressure exerted by the water in the air is higher, so the water molecules move from the air to the desiccant and the air is dehumidified. Dehumidifier consists of silica desiccant bed, fans and reactivation heater. Desiccant dehumidifier dry and increase the temperature of the process air which is further introduced in the dying chamber. The fans at both side (process and reactivation side), used to suck and blow the air. The reactivation takes place at reactivation side of the dehumidifier and the reactivation heater is used to heat the reactivation inlet air and then the hot air is used to regenerate the desiccant bed.

Fig.1 Rotary bed desiccant dehumidifier

2.3 Desiccant material

A range of materials are used for today's desiccant rotor constructions. The synthetically-produced silica gel is a fine pored solid silicic acid which consists of 99 % silicon dioxide. It can adsorb up to 40 % of its dry weight in water when in equilibrium with air at saturation. Silica gel can withstand temperatures up to 400°C and is a solid, insoluble desiccant. No special precautions are required when it is exposed to air at 100 % relative humidity. It is also possible to wash a wheel in water if dust or other particulate block the air passageways. Silica gel does not undergo any chemical or physical change during the adsorption process. It is inert, non-toxic, stable and resistant to most chemicals.

2.4 Drying system

Desiccant dehumidifier dryer consisting of a desiccant dehumidifier and drying chamber was developed (Figure 2). The drying chamber connected to dehumidifier by flexible pipes. The drying chamber made up of plywood and consists of five trays arranged one over the other with sliding rollers, plenum chamber, air inlet and chimney. Low humidity is maintained during drying ranges from 17-20 % and the drying temperature of 45°C were selected for drying, keeping in view the product quality as well as time required for drying. For comparison of drying time and quality of dried product samples were also dried in tray dryer at same drying air temperature.

Fig.2 Desiccant based food dryer

2.5 Moisture Content

The moisture content of fresh and dehydrated fenugreek green was determined by standard hot air oven method by using a weighing balance with 0.01 g sensitivity [11]. The loss in weight during drying was used to calculate the moisture content of the sample during drying.

2.6 Ascorbic acid

Ascorbic acid is also known as vitamin-C and it was determined by 2, 6-dichlorophenol-indophenol visual titration method [12] and the procedure for estimation of ascorbic acid is calculated by equation 1.

$$\textbf{Ascorbic acid (mg per 100 g)} = \frac{AXBXVX100}{WXaliquot\ of\ the\ extract\ taken} \quad \mathbf{1}$$

where A is volume in mL of standard dye used for titration; B, weight in mg of ascorbic acid equivalent to 1mL of indophenol solution, i.e., dye factor; V is total volume; and W, weight of sample in g.

2.7 Total carotenoid

Carotenoids are primarily responsible for photosynthesis in plants. The green leafy vegetable like fenugreek green is rich source of Carotenoids contents. Total Carotenoids is calculated by (equation 2) column chromatography after that the readings of optical density were taken by spectrophotometer [13].

$$\textbf{Total carotenoid (mg/100g)} = \frac{OD\ at\ 450\ nm \times volume\ made\ up}{250 \times weight\ of\ sample} \times 100 \quad \mathbf{2}$$

2.8 Rehydration Ratio

Every dried product cannot be consumed directly. Most need to be rehydrated by soaking in water prior to consumption. There are several factors affecting rehydration, such as the soaking period, temperature of the water, and the rehydration capacity of the product. The rehydration capacity can be influenced by the drying process. Drying processes that change product composition to a lesser extent are supposed to offer better rehydration ratio of finished product. For rehydration capacity, pre-weighed samples were soaked in ample amount of water for 30 minutes at room temperature and calculated by equation 3. This steeping is known as re-hydration. The ratio of mass of re-hydrated and dehydrated samples can be used to find following re-hydration characteristics [12].

$$\textbf{Re-hydration ratio } RR = \frac{A}{B} \quad 3$$

Where,

A	=	**Weight of re-hydrated sample (g)**
B	=	**Test weight of dehydrated sample (g)**

2.9 Organoleptic Score

Organoleptic evaluation is important to assess the consumer's requirements. It is difficult to classify 100% by machine because it is a subjective factor. Dehydrated products should have a typical color, appearance, aroma and texture. Organoleptic evaluation was also done on the basis of color, appearance, aroma, texture and overall acceptability.

III. Result And Discussion

3.1 Performance of desiccant dehumidifier for continuous operation.

Adsorption study of desiccant dehumidifier was carried out throughout the day and the results presented in Figure 3. The experiment was conducted at regeneration temperature of 100°C and air mass flow rate of 0.63 kg/s. The process in temperature increased from 32.9°C at 10:00 hrs to 37.5°C at 14:00 hrs and then decreased to 34.7°C at 17:00 hrs whereas the process in relative humidity deceased from 47.65 % at 10:00 hrs to 33.04 % at 15:00 hrs and then increased to 36.40 % at 17:00 hrs. The average values of process in temperature and relative humidity were 35.8 °C and 38 %, respectively. The process out temperature was increased from 46.8°C at 10:00 hrs to 51.0°C at 14:00 hrs and then decreased to 48.2°C at 17:00 hrs whereas the process out relative humidity decreased from 17.86 % at 10:00 hrs to 11.86 % at 16:00 hrs and then increased to 12.4 % at 17:00 hrs. The average values of process out temperature and relative humidity were 49.1°C and 14.1 %, respectively.

The experimental results indicate that temperature and relative humidity of process out depends on the process inlet conditions. Initially the temperature is low at both sides and then starts increasing and then decreases in the evening hours. The process out temperature increases with increase in process inlet temperature and decreases with decrease in process inlet temperature and similarly the relative humidity. Initially the relative humidity is higher at process in and out then it starts decreasing at both sides and there is increase in the relative humidity in the evening at the end of experiment.

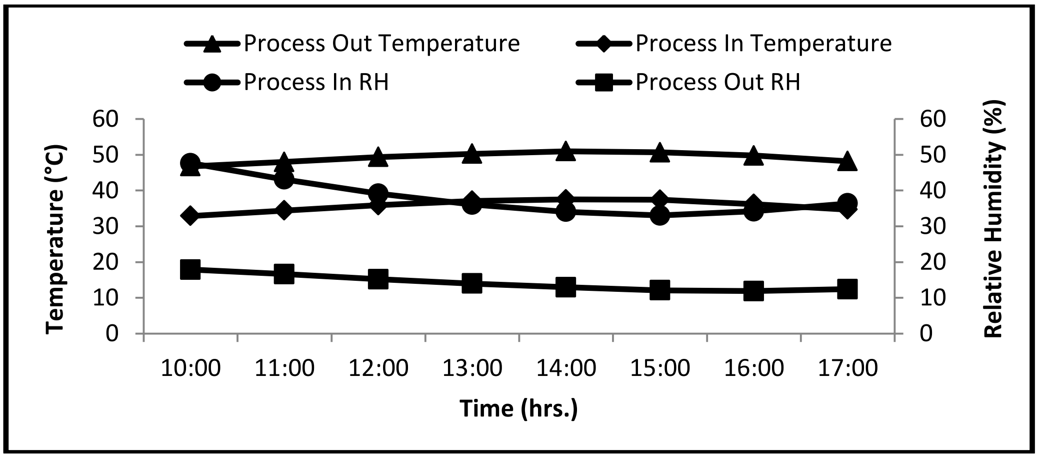

Fig.3 Variation in temperature and RH at the process in and process out throughout the day

3.1.1 Adsorption Capacity

Adsorption capacity is the capacity of the desiccant wheel to adsorb moisture on the surface and it is the difference between process inlet and process out absolute humidity as shown in Fig.4. It was observed that the maximum adsorption capacity in process side is 3.5 g/kg dry air at 60°C regeneration temperature and process air flow rate of 0.32 kg/s. The adsorption capacity decreased to 2.4 g/kg dry air at an air mass flow rate of 1.30 kg/s and regeneration temperature of 60°C. The minimum adsorption capacity at process side is 1.1 g/kg dry air at 120°C regeneration temperature and process air flow rate of 0.32 kg/s likewise at the regeneration temperature of 120°C and airflow rate 1.30 kg/s, the adsorption capacity decreases to 0.2 g/kg dry air. The results showed that the average value of adsorption capacity at process side is 2.0 g/kg dry air. The average adsorption capacity throughout all the regeneration temperature follows 2.5, 2.2, 1.9 and 1.6 g/kg dry air at air flow rates 0.32, 0.63, 0.95 and 1.30 kg/s, respectively. The difference between the adsorption capacity for higher and lower regeneration temperature at lower (0.2 g/kg of dry air) at higher regeneration temperature and air mass flow rate of 120°C and 1.30 kg/s air mass flow rate of 0.32 kg/s was 2.4 g/kg of dry air and for 1.30 kg/s of air mass flow rate the difference was 2.2 g/kg of dry air. The adsorption capacity in process side was (3.5 g/kg of dry air) higher at lower regeneration temperature and air mass flow rate of 60°C and 0.32 kg/s and was.

It is also observed from Figure 4 that the adsorption capacity at process side decreases with increase in process air mass flow rates. Increase in process inlet air velocity leads to reduction in adsorption capacity at process side due to lesser contact of inlet air on the desiccant surface. At air mass flow rate of 0.32 kg/s, the desiccant dehumidifier give better moisture removal capacity. The adsorption capacity at regeneration temperature of 60°C and process air mass flow rate of 1.30 kg/s was 2.4 g/kg dry air whereas for the same reactivation temperature and the process inlet velocity of 0.32 kg/s, the adsorption capacity is 3.5g/kg dry air.

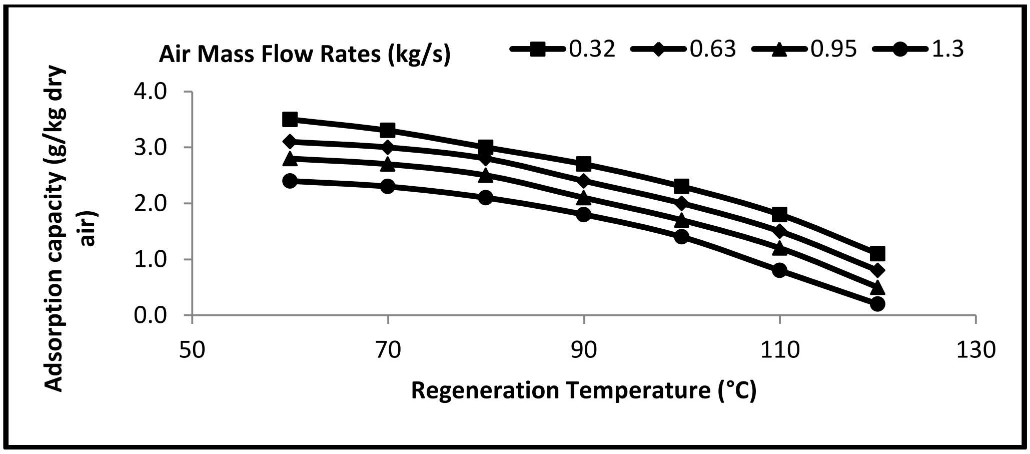

Fig. 4 Effect of regeneration temperature on moisture holding capacity at process side at different air flow rates.

3.1.2 Desorption Capacity

Moisture removal capacity at reactivation side (desorption capacity) is the capacity of the desiccant wheel to desorbs moisture from the desiccant bed surface and it is the difference between reactivation out and reactivation in absolute humidity. Fig. 5 shows that the desorption capacity at reactivation side increases with increase in regeneration temperatures at every air mass flow rates.

The minimum desorption capacity in reactivation side was 0.8 g/kg dry air at regeneration temperature of 60°C and process air mass flow rate of 0.32 kg/s likewise at the regeneration temperature of 60°C and air mass flow rate 1.30 kg/s, the desorption capacity increases to 2.0 g/kg dry air. The minimum desorption capacity at reactivation side is 3.5 g/kg dry air at regeneration temperature of 120°C and process air mass flow rate of 0.32 kg/s likewise at the regeneration temperature of 120°C and air mass flow rate of 1.30 kg/s, the desorption capacity increases to 4.7 g/kg dry air. The results further showed that the average value of desorption capacity at reactivation side was 2.5 g/kg dry air. The average desorption capacity throughout the experiment and for all the regeneration temperatures was 1.9, 2.2, 2.6 and 3.1 g/kg dry air at air flow rates of 0.32, 0.63, 0.95 and1.30 kg/s, respectively.

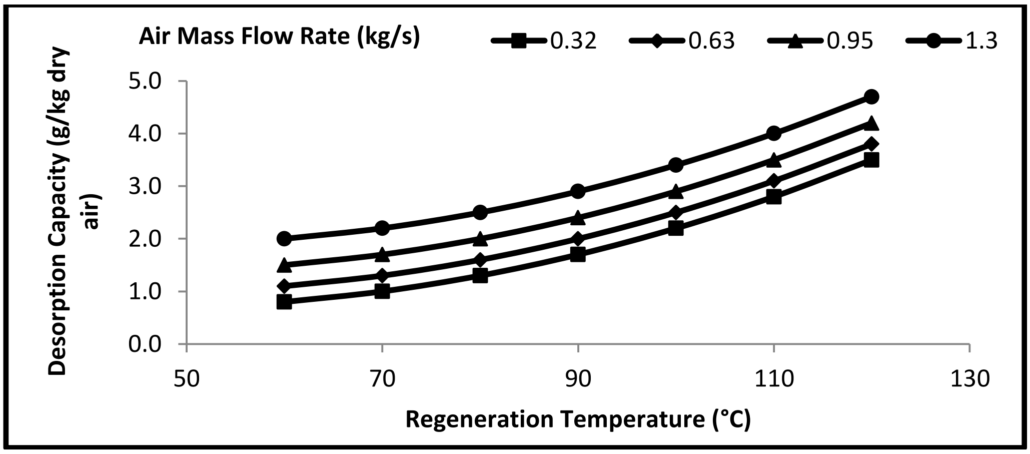

Fig. 5 Effect of regeneration temperature on reactivation moisture removal at different air flow rates

3.2 Variation in moisture content and with time for desiccant dryer and tray dryer

The variation of moisture content with time for fenugreek green at drying air temperature of 45 °C for desiccant dryer and tray dryer is presented in Figure 6. In the starting of the experiment the initial moisture content was 88.60 % (wb), then its starts decreasing with time. Drying was conducted on drying air temperature of 45 °C. The drying time was higher in tray dryer as compare to desiccant dryer. Desiccant dryer and tray dryer took 600 and 720 minutes, respectively to dry fenugreek green to equilibrium moisture content of 5 % from initial moisture content of 88.60 %. The drying time was higher in tray dryer as compared to desiccant dryer.

3.3 Rehydration characteristics of dehydrated fenugreek green

Rehydration is a complex phenomenon affected by numerous factors. Important factor that would affect the rehydration is the changing of cell structure during the drying process. In most cases, the changing of cell structure is related to drying product temperature. Table 1 shows that the rehydration ratio was high in desiccant dried product as compare to tray dryer at 45 °C. Rehydration ratio for desiccant dryer was 3.8 g/g and for tray dryer 3.0 g/g at drying temperature of 45°C. It was found that the rehydration ratio of the fenugreek green dried in low temperature and humidity based desiccant dryer were higher as compare to tray dryer. So, we can say that desiccant dehumidifier is suitable for food dying.

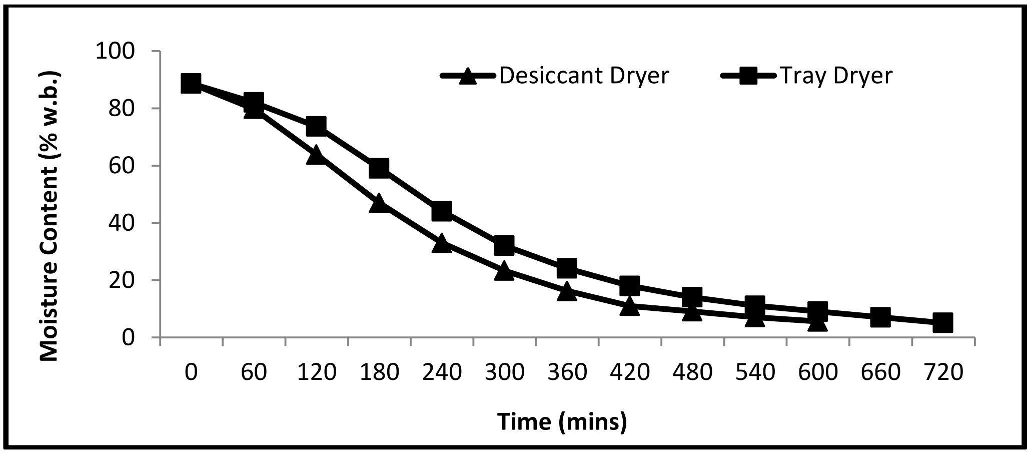

Fig.6 Variation of moisture content with drying time for fenugreek green for desiccant dryer and tray dryer

Table 1. Effect of drying air temperature on quality parameter of dehydrated fenugreek green at 45 °C

Sr. No.	Drying Systems	Temperature (°C)	Rehydration Ratio (g/g)	Carotenoids (mg/100g)	Ascorbic acid (mg/100g)
1.	Fresh fenugreek green	ND	ND	32.4	209.2
2.	Dehumidifier Dried	45	3.8	25.2	192.4
3.	Tray Dried	45	3	12.2	170.5

3.4 Retention of vitamin contents in dehydrated fenugreek green

The fresh fenugreek greens contained 209.2 mg/100 g ascorbic acid and 32.4 mg/100g of total Carotenoids. It is observed from the Table1 that the ascorbic acid retention among the dehydrated samples was maximum192.4mg/100g in desiccant dehumidifier dried fenugreek greens and 170.5 mg/100g in tray dried sample at drying air temperature of 45°C. Desiccant drying helped retention of carotenoids and ascorbic acid content than tray drying. Table 1shows that the carotenoids retention among the dehydrated fenugreek green was 25.2 mg/100g in desiccant dried fenugreek green and 12.2 mg/100g in tray dried sample at drying air temperature of 45°C.

3.5 Organoleptic evaluation

Organoleptic evaluation was also done on the basis of color, appearance, aroma, texture and overall acceptability and results shown in Fig.7. Organoleptic score for color, appearance, aroma, texture and overall acceptability for desiccant dried fenugreek green at drying temperature of 45°C was 9, 7.9, 8, 8.1 and 8.2, respectively whereas the score for tray dryer under similar conditions of temperature was recorded as 8, 7.5, 7.6, 7.9 and 7.8. Organoleptic score for tray dried fenugreek green came out to be lower than that of desiccant dried fenugreek green.

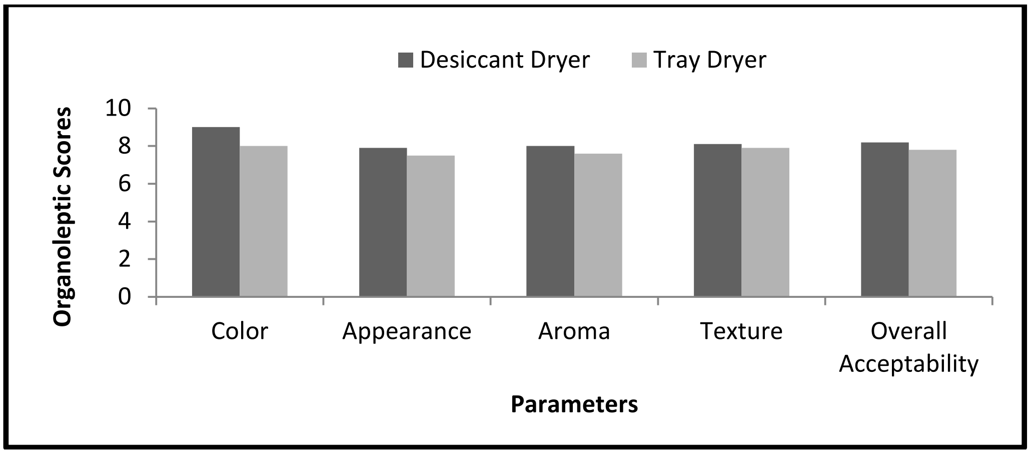

Fig. 7 Overall acceptability of desiccant and tray dried fenugreek green

IV. Conclusion

A fast, desiccant-based low-temperature drying system with temperature and airflow control was presented and evaluated. The drying can be carried out throughout the day and night it is a continuous drying process which does not depend on day light to gain heat from sun. Desiccant dryer can also be used in adverse climatic conditions which reduce drying time and dry the product faster as compare to conventional drying system. The main purpose of desiccant dehumidifier is to reduce the moisture content from the process inlet air and increases its temperature which is further used for drying. The low humidity air has maximum capacity to gain moisture when it forced through food product leads to absorption of moisture from the wet food product.

Desiccant food drying system can be used for drying various agricultural products, efficiently and economically without compromising with environmental conditions. The regeneration temperature and air flow rate of the dehumidifier was controlled to maintain constant optimal temperature (45 °C) and uniform drying rates within the drying chamber. Low temperature dried fenugreek green retain a large proportion of the vitamin C and carotenoids content. Drying was achieved faster in desiccant dryer as compared to tray dryer.

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