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Optimization of Process Parameters for Convective - Microwave Drying of Ashwagandha Roots

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Abstract
Application of microwave for drying of ashwagandha roots was investigated. A laboratory convective - microwave dryer was already developed which had the provision of regulating of air temperature, air velocity and microwave power. Ashwagandha roots of uniform size were used in the drying experiment which were carried out at air temperatures of 40, 50 and 60°C, air velocities of 1.0 and 1.5 m/s and microwave power levels of 2, 4 and 6 W/g. Convective- microwave drying was accomplished till the moisture content of the ashwagandha roots reduced from initial moisture content of 5.06 kg water/kg of dry matter to a safer level of 0.06 kg water/kg of dry matter. The effect of power level increment of convective -microwave drying was reduced the drying time thereby increased the drying rate. The quality attributes of fresh and dehydrated ashwagandha roots were evaluated for colour changes (L, a, b values), total alkaloids content and rehydration ratio. The samples of sun dried ashwagandha roots were obtained and the quality attributes of this sample was compared with products dried by convective -microwave drying technique. The quality of ashwagandha roots dehydrated by convective -microwave drying was found to be superior to the sun drying process. Page model was found to be best fit for convective - microwave drying condition. The process parameters were optimized by using statistical analysis ANOVA for responses with significant model and non significant lack of fit. The optimum operating conditions of ashwagandha roots for power level, velocity and air temperature in convective-microwave drying process were 6 W/g, 1.5 m/s and 50°C, respectively and found a good quality of dehydrated ashwagandha roots. Corresponding to values of process variables i.e. 6 W/g, 1.5 m/s and 50°C, the values of rehydration ratio, total alkaloids content, less ΔE were 4.16, 1.94 % and 5.654, respectively.

Keywords: Ashwagandha roots; Convective -microwave drying; Rehydration ratio; Total alkaloids content; Colour change

I. Introduction

Ashwagandha [*Withania somnifera* (Solanaceae)] is an important medicinal plant, widely used as health food and home remedy for several diseases in India as well as other parts of the world and the interest of medicinal plant products across the world has increased significantly in recent years. According to WHO survey, about 40-50% of the world population relies on non conventional medicine for their primary health care and is described as an herbal tonic in Vedas and considered as Indian Ginseng in traditional Indian system of medicine. Ashwagandha root contains nicotine and group of alkaloids and also contains the different ingredients i.e. foreign matter (Not more than 2%), total ash (7%), acid soluble ash (1%), alkaloids(2.5%) and water (80%)(Baraiya, 2004). In ashwagandha, the root parts contain more active ingredients, volatile oil, flavour and alkaloids as compared to the other parts of the plants (Prasad et al. 1986).The dehydrated ashwagandha root is used for curing of different diseases such as tumors, inflammation (including arthritis), anemia, breathing difficulties, cancer, cough, insomnia, paralysis, ulcers, memory loss, women's health, skin disease, eyesight, pains and a wide range of infectious diseases and also being used as food, cosmetic and pharmaceutical industries. Drying is one of the oldest and most widely used methods of food preservations because of longer shelf life, better quality, product diversity and substantial volume reduction of dried products. In India, ashwagandha roots are dried by small scale industries using by sun drying in the open field without any aseptic conditions and in this process, it requires more time around 3 to 5 days for drying depends upon the weather conditions and gets poor quality of the final products. So, natural drying is being replaced by artificial drying process in which to reduce drying time as well as post harvest infection. In recent years, microwave drying has been popularly used as drying method for a number of food products such as fruits, vegetables, snack foods, dairy products and medicinal roots, etc. Microwaves drying is relatively a new addition in the existing drying technique viz. hot air, cabinet, spray, vacuum and freeze drying(Prabhanjan *et al.* 1995; Ren and Chen (1998).Microwaves are rarely used alone but rather in combination with hot air, steam, vacuum conditions or the conventional methods have more synergistic effect. Two narrow band of microwave allotted for use in industrial food processing application are 915 and 2450 MHz which can be absorbed by water containing materials and converted to heat (Khraisheh *et al.*, 1997). Waves can penetrate directly into the material; heating is volumetric (from the inside to outside) and provides fast and uniform heating throughout the product. The quick energy absorption by water molecules causes rapid evaporation of water creating an outward flux of rapid escaping vapour. Microwaves penetrate the food from all direction which facilitates steam escape and speed heating. In addition to improve the rate of drying, this outward flux can help prevent the shrinkage of tissue structure, which prevails in most conventional air drying technique. Hence, better rehydration characteristics may be expected in microwave dried products (Prabhanjan *et al.*, 1995). Microwave processes offer a lot of advantages such as less start up time, faster heating, energy efficiency (most of the electromagnetic energy is converted to heat), space savings, precise process control and food product with better nutritional quality. Mathematical modeling can be played an important role in the design and control of the process parameters during microwave drying and should be reduced to a state where it describes the most effective way of modeling. The developed model is used to calculate the dependent parameters at drying process parameters. From the correlation coefficients (R^2) and the percent error, these models are tested for statistical viability at the 1% level of significance (Khraisheh *et al.*, 1999).Statistical analysis by ANOVA is used to check the significance of the process parameters on the dependent parameters as per Panse and Sukhatme (1967).Most research work on combined microwave connecvective drying of agricultural commodities has been reported for low moisture food products.but, ashwagandha root is a high moisture commodity and having medicinal value, it requires mild heat for shorter period drying. So, the development of convective -microwave drying that reduces the drying time and produces good quality of ashwagandha roots could make significant contribution to the pharmaceutical industries and promotes the export of dehydrated ashwagandha roots as well as powder. However, very little work has been undertaken in India under hot air drying of medicinal roots and also there exists no work on the convective - microwave drying of medicinal roots of ashwagandha.Present investigation has been aimed to study the effect of convective - microwave drying behavior as well as the quality of ashwagandha root at various air temperature, air velocity and microwave power levels and to optimize these process parameters.

II. Materials and Methods

Fresh ashwagandha root having initial moisture content 80-85% (wb) with minimum maturity four months were procured from medicinal farm of Kharagpur in the state of West Bengal (India) used in the present investigation. The initial moisture content of ashwagandha root had 4.5 to 5.0 g water /g dry matter and were stored in a cold storage chamber maintained approximately at 15^0 C temperature and 85 % relative humidity.

Moisture content:

The vacuum oven method was used to determine the moisture content of ashwagandha root. The roots samples of approximately 30 g were placed in a predried aluminum dishes in vacuum oven. The operating temperature was taken as that of 70^0C at negative pressure of 13.3 kPa and the sample was taken out of oven after 24 h (Young & Mason, 2002). The samples were cooled in desiccator and weighed using an ANAMED top pan electric balance with a sensitivity of 0.01 g. The fresh and bone dried roots weights were taken to calculate the moisture content expressed as g water /g dry matter.

Experimental procedure

Ashwagandha root were taken out from cold storage and allowed to maintain equilibrium with ambient conditions. Roots were washed thoroughly and samples were cut in 5cm length under the hygienic conditions and 100g of each sample was used for drying experiment. Prior to drying, samples were pretreated with hot water at 100^0C for 2 mins to improve the quality of the dehydrated product. A 900W, 2450 MHz microwave oven (IFB make, model Electron) having inside chamber dimension of 300(width) $\times$ 240(depth) $\times$210(height) mm^3 was used for the experiment (Sharma & Prasad, 2001).The oven had the facility to adjust power supply and the time of processing. A variac of 15 A/230 V rating was also placed on the primary side of the high voltage transformer to regulate the anode current, thus varying the output power of the magnetron between 0 and 600 W with 5 duty cycles or settings. Calibration of Microwave Power level was done using potable water in the dryer to set the desire drying conditions before start the experiment. The hot air was sucked by the blower through the heaters and was thrown into the drying chamber. These chambers had a screen at the bottom with approximate 1 mm hole diameter. The temperatures were measured by thermometer. The air velocity was measured by an anemometer (Make: Kanomax, Japan) with a least count 0.1m/s. The convective - microwave drying experiments were carried out at different microwave power levels of 2, 4 and 6 W/g, at air velocities of 1.0 and 1.5 m/s and air temperatures of 40, 50 and 60^0 C. The samples were placed inside the microwave cavity. The drying was performed according to the preset power and time schedule. The weight loss of the roots was determined after every 1-5 min until it reached to a moisture content of about 5-6% (db). The samples were allowed to come to room temperature, packed and stored. Three replications were taken for each experiment to get an average values. The sample weight loss during drying was to be co-related with moisture content on dry basis and expressed as kg water/ kg dry matter. The drying data were then analyzed to study the drying behavior of ashwagandha roots.

III. Analysis of Drying Data

The observed drying data i.e., weight loss of the sample with time for each drying run were converted into different parameters such as moisture content (kg water/kg dry matter) and drying rate (kg water/kg dry matter/min) and moisture ratio (MR). The moisture content of the sample was calculated from the weight of the sample measured at different times during the course of drying and was expressed on dry mater basis.

$$\mathrm{M} = \frac{X_w}{X_f} \quad \ldots (1)$$

Where, M = moisture content of the sample, kg of water/kg of dry matter

X_w = weight of moisture in the sample, kg, X_f =weight of dry matter in the sample, kg

Modeling of Drying Data

Models are widely reported in the literature for the purpose of simulation and scale up of the process. The empirical Page's equation (2) has been used to describe the drying process with drying kinetics of agricultural commodities.

$$MR = \frac{M - M_e}{Mo - M_e} = \exp(-kt^n) \quad \ldots (2)$$

Where, MR = moisture ratio = (M -Me)/ (M_0 -Me); M =moisture content (kg water/kg dry matter) at time t, Me = equilibrium moisture content (kg water/kg dry matter); M_0 = initial moisture content (kg water/kg dry matter) at time = 0; K = drying rate constant (min^{-1}); n is the parameter of Page's model; and t = drying time in min.

Quality evaluation of dehydrated ashwagandha root

The quality of ashwagandha roots samples dried by convective - microwave drying and sun drying conditions, were evaluated by measuring rehydration ratio, total alkaloids content and colour changes adopting the standard procedure described below.

Colour change:

Colour is one of the important parameters, which is an indicative of the commercial value of the product. The basic purpose was to get an idea of the comparative change in colour of fresh and dried material. The colour changes of ashwagandha roots were measured before and after drying by using chromameter.The colour values were expressed as L*(Whiteness/darkness), a* (redness/greenness) and b*(yellowness/blueness) and the total colour difference from the fresh ashwagandha root ΔE, as defined the following, was used to describe the colour change during drying:

$$\Delta E = \sqrt{\left\{ \left(L_o^* - L^*\right)^2 + \left(a_0{}^* - a^*\right)^2 + \left(b_0{}^* - b^*\right)^2 \right\}} \quad ---(3)$$

Subscript "o" refers to the colour reading of fresh Ashwagandha roots, *L**, *a**and *b** indicate brightness, redness and yellowness of dried samples respectively. Fresh Ashwagandha root was used as the reference and larger ΔE denotes: greater colour change from the reference.

Total alkaloid content

The standard procedure was adopted to determine the total alkaloids extraction (Govt. of India, 1986) and (Owais et al., 2005).Dragandorf's Reagent was prepared using Solution 1 and Solution 2. Solution 1 was prepared by dissolving 2 g Bismuth oxy Nitrate in 40 ml of water and 10 ml of acetic acid and Solution 2 was prepared by dissolving 2.8 g of Potassium Iodide in 20 ml of water. Equal volumes of Solution 1 and Solution 2 were mixed and 10 ml of the resultant mixture was added to 100 ml of water and 20 ml of acetic acid. Dried ashwagandha root was made powder by using laboratory grinder and accurately 5 g powder was taken. Sample was completely immersed in 90 % alcohol for overnight. Extract was then prepared using soxtherm. Solvent was evaporated at 60^0 C and concentration solution was serially washed with 25, 20, 15 and 10 ml portion of 5% Sulphuric Acid and treated with excess Dragandorf's reagent followed by Acetone (1 ml).The Acetone solution was treated with freshly prepared suspension of 2 g Silver Carbonate. The solution was filtered and the precipitate was washed with Acetone, Alcohol and water in order. After filtration, sufficient Hydrogen Sulphide was passed and the solution was boiled for 10 minutes; filtered and evaporated under water bath at 60 ^{0}C till constant weight was reached. The alkaloids content was expressed in per cent.

Rehydration ratio:
Rehydration ratio for the dehydrated ashwagandha roots was carried out in triplicate, by immersing of convective -microwave dried as well as sun dried sample in water. The ashwagandha roots obtained after 5 h of rehydration were evaluated for rehydration ratio.Approximetely 5 g dried sample was put in 50 ml distilled water in a 100 ml beaker kept in a hot water bath to maintained water temperature of 35^0 C for 5 h. The water of the beaker was drained and the sample was removed. Surface moisture was wiping it off with a tissue paper and the weight was taken (Sharma & Prasad, 2001, Ranganna, 1986).Rehydrated ashwagandha roots were evaluated using the following formula:

$$\text{Rehydration ratio (RR)} = \frac{W_r}{W_d} \quad \ldots\ldots\ldots\ldots (4)$$

Where, W_r =weight of Rehydrated ashwagandha roots, g

W_d = Weight of the dried roots, g

Statistical analysis by ANOVA was carried out to find the significant effect of process parameters at 1% level of significance on the quality parameters as per Panse and Sukhatme (1967).

IV. Results and Discussion

Effect of process variables on drying time and drying rates for convective - microwave drying:
Total drying times involved to reduce the moisture content in convective - microwave drying of ashwagandha roots from an initial moisture level to a safer level of about 0.06 kg water /kg dry matter, under various drying conditions are presented in different figures. The change in the moisture content of ashwagandha roots with elapsed drying time, at each of the drying temperatures of 40, 50 and 60°C , air velocity of 1.0 m/s and power levels of 2 W/g, drying temperatures of 40, 50 and 60°C , air velocity of 1.5 m/s and power level of 2 W/g , drying temperatures of 40, 50 and 60°C , air velocity of 1.0 m/s and power level of 4 W/g, drying temperatures of 40, 50 and 60°C , air velocity of 1.5 m/s and power level of 4 W/g, drying temperatures of 40, 50 and 60°C , air velocity of 1.0 m/s and power level of 6 W/g, drying temperatures of 40, 50 and 60°C , air velocity of 1.5 m/s and power level of 6 W/g are presented in figure 1,2,3,4,5 and 6 ,respectively. The minimum drying time to reduce the moisture content about 5.06 kg water /kg dry matter to final moisture 0.06 kg water /kg dry matter was found in drying air temperature of 60°C, air velocity of 1.5m/s and power level of 6 W/g (Fig.6) and the maximum drying time was found at air temperature of 40°C,air velocity of 1.0 m/s and power level of 2 W/g (Fig.1).The moisture content decreased exponentially with elapsed drying time under all drying conditions and the drying behaviour was followed the typical trend of the drying curves for food materials earlier reported by many researchers ((Prabhanjan *et al.* 1995; Ren and Chen, 1998; Sharma & Prasad, 2001). The drying rate curves of Ashwagandha roots as a function of drying time at different air temperatures, air velocity and power level i.e. (40, 50 and 60°C , 1.0m/s and 2 W/g),(40, 50 and 60°C , 1.5 m/s and 2 W/g), (40, 50 and 60°C , 1.0m/s ,4 W/g), (40, 50 and 60°C , 1.5 m/s and 4 W/g),(40, 50 and 60°C , 1.0m/s and 6 W/g), (40, 50 and 60°C , 1.5 m/s and 6 W/g) are presented in figure 13,13,14,15,16 and 18, respectively. As the drying air temperature increased at a given power level, the drying curved exhibited a steeper slope for all convective-microwave drying conditions, implying that drying rate decreased with increased in drying air temperature. This resulted substantial decrease in drying time (t) when higher air temperatures were used (Fig.18). Increase in air drying temperature increased the drying rates, thereby reduced the drying time. The total drying time decreased at all drying air temperatures when the air velocity was increased from 1.0m/s to 1.5 m/s. Such a trend has also been reported earlier for carrot (Prabhanjan *et al.* 1995), grapes (Tulasidas *et al.* 1995), the American ginseng roots (Ren and Chen, 1998), banana (Maskan, 2001), kiwi fruits (Maskan, 2001) and garlic(Sharma & Prasad, 2001).

Effect of microwave power level:
The effect of microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.0 m/s and air temperature of 40^0 C, microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.5 m/s and air temperature of 40^0 C, microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.0 m/s and air temperature of 50^0 C, microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.5 m/s and air temperature of 50^0 C, microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.0 m/s and air temperature of 60^0 C and microwave power levels of 2, 4 and 6 W/g, at air velocity of 1.5 m/s and air temperature of 60^0 C on the drying of ashwagandha roots has shown in the figure i.e. 7,8,9,10,11 and 12,repectively. In all the cases, the drying time reduced with the increase in microwave power level. The increase in power level (PL) increased the temperature of the product, which increased the vapour pressure inside the product resulting for all the set in faster drying. Thus, the drying time was

reduced of experiments by varying the power levels from 2 W/g to 6 W/g.

Effect of air velocity:

The figure numbers from 7 to 12 also suggested that the drying air velocity (v) affects the drying time of ashwagandha roots. It is quite clear from these curves that the increase in air velocity reduced the drying time in convective-microwave drying of ashwagandha roots. The drying is attributed to the increase in the heat and mass transfer coefficients at the evaporating surface with the increase in air velocity for a given air temperature. It is evident from figures that at given air temperature and microwave power level, the increase in air velocity increased the drying time.

Modeling Drying Curves:

The Page model was employed to describe the drying kinetics of ashwagandha root by convective –microwave drying method. Moisture ratio (MR) data for convective- microwave drying of ashwagandha roots was tabulated in Table 1 used to test the applicability of the Page model and the predicted moisture ratio by Page model was shown in figure numbers from 19 to 24. The parameters k and n of Page equation was evaluated by data analysis using excel. The analysis yielded high values of R^2 ($R^2 > 0.9$) for convective -microwave drying method which was found to be in good agreement with the previous findings (Maskan, 2000; Sharma & Prasad, 2001). It is evident from the Table 1 that the rate constant 'k' increased with increase in drying air temperature satisfying higher drying rates at higher temperatures as well as the same trend for 'k' was also observed at both the air velocities. It could be expected that at constant air temperature, an increase in the air velocity resulted in higher value of 'k' because of increase in the outside film heat transfer coefficient (Sharma and Prasad, 2001). The drying rate constant was found to increase significantly as the drying time was reduced in convective-microwave drying with process parameters.

Optimization of process parameters:

Quality attributes of ashwagandha roots dried by convective - microwave drying in respect of rehydration ratio and total alkaloids content are presented in Table 2 and quality attributes of ashwagandha roots dried sun drying in respect of rehydration ratio and total alkaloids content are presented in Table 3. The evaluation of colour changes for convective–microwave drying are presented in Table 8 and for sun drying, it is presented in Table 7.The sample of sun dried ashwagandha roots was served as a control for quality evaluation of convective- microwave drying process. It can be inferred that the most favourable parameters for rehydration ratio, total alkaloids content and colour changes was found 6 W/g of microwave power level, an air velocity of 1.5 m/s and air temperature of 50^0 C for convective-microwave drying (Table 2) as compared to sun drying. The microwave power increment from level 2 W/g to 6 W/g helped to raise the rehydration ratio for all the experiments due to the increased power level reduced the drying time appreciably to contribute faster drying and hence good rehydration of the final product. The higher rehydration ratio was found in case of convective-microwave dried sample because of less case hardening in microwave heating as compared to sun drying. When the dried sample was put into water, the volume of absorbed water increases with increasing rehydration time, irrespective of the power level, temperatures, air velocities and sizes (Sharma and Prasad, 2001).Statistical analysis by ANOVA (Tables 4 to 6) was adopted to find the significant effect of the process parameters (microwave power level, air temperature and air velocity) on the quality attributes (rehydration ratio and alkaloids content) for convective-microwave drying methods to determine how drying time and quality parameters are related to optimize the process per Panse and Sukhatme (1967).The Design summary of convective - microwave drying of ashwagandha roots are presented in Table 4.The model F values on the effect of process parameters on rehydration ratio (Table 5)and total alkaloids content(Table 6) were found significant at 1% level of significance for convective–microwave drying(Table 5). The power level, temperature and air velocity are significant model terms when rehydration model was taken into consideration where as the model term power level (W/g) was not found to be significant when total alkaloid content was taken into consideration. The colour changes of convective-microwave drying sample of ashwagandha root was much lighter (higher L* value) than the sun dried product. The total colour change (ΔE) values of ashwagandha root were compared with sun drying and convective-microwave drying. Convective-microwave caused little and sun drying caused more colour change among the drying methods.

V. Conclusion

It is possible to dry ashwagandha roots by combined convective-microwave drying of ashwagandha roots found to be faster than sun drying. The drying data of convective-microwave drying conditions was best fitted by Page model. The effect of process parameters on rehydration ratio and total alkaloids content was found significant at 1% level of significance in convective-microwave drying method. In convective-microwave drying, the optimum conditions for good colour and rehydration ratio and total alkaloids content were power level of 6 W/g, velocity of 1.5 m/s and air temperature of 50° C. Extraction of total alkaloids from Ashwagandha roots was maximum in case of convective-microwave drying (1.94%) followed by and sun-drying (1 .54 %).

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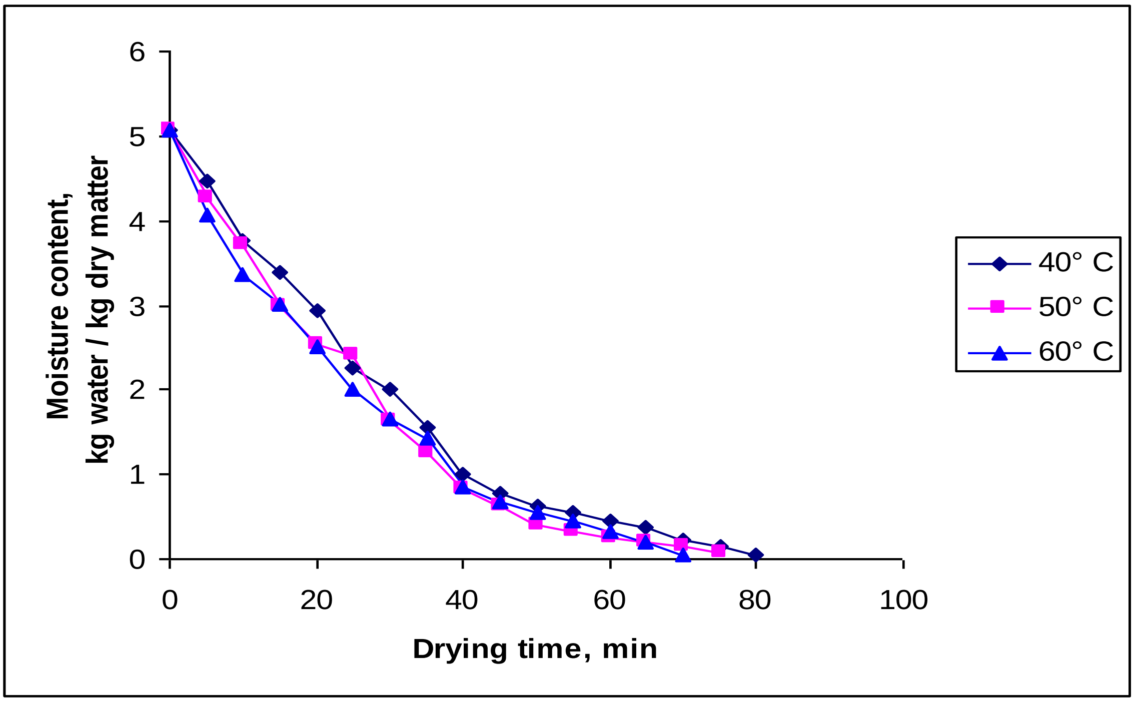

. Fig.1: Moisture content vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 2 W/g power level

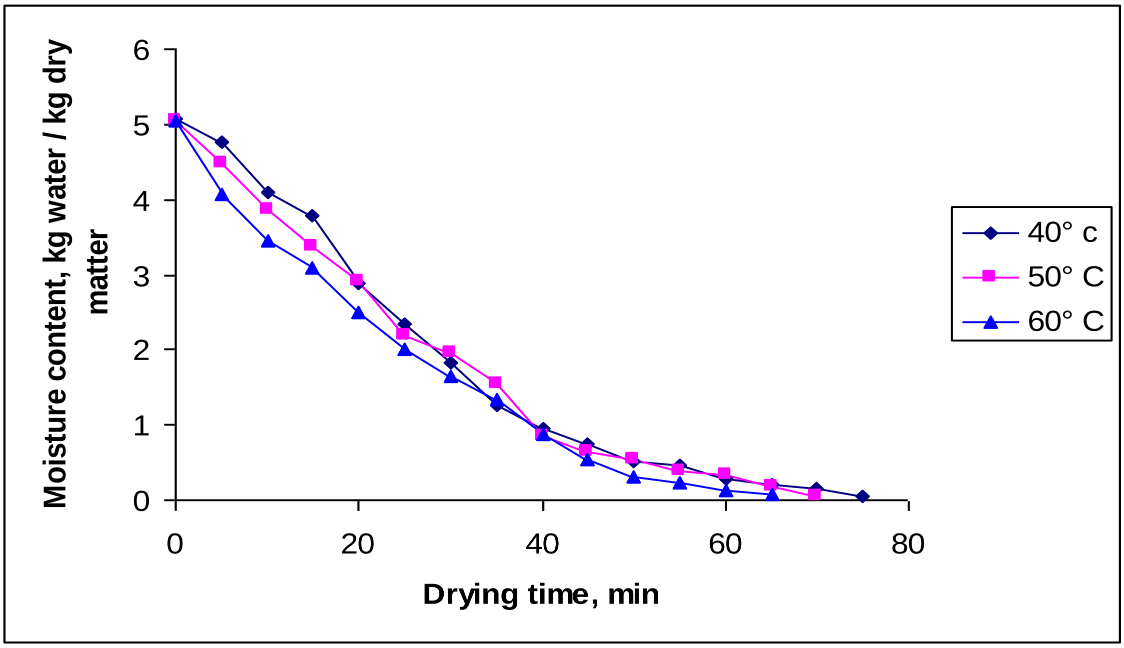

Fig.2: Moisture content vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 2 W/g power level

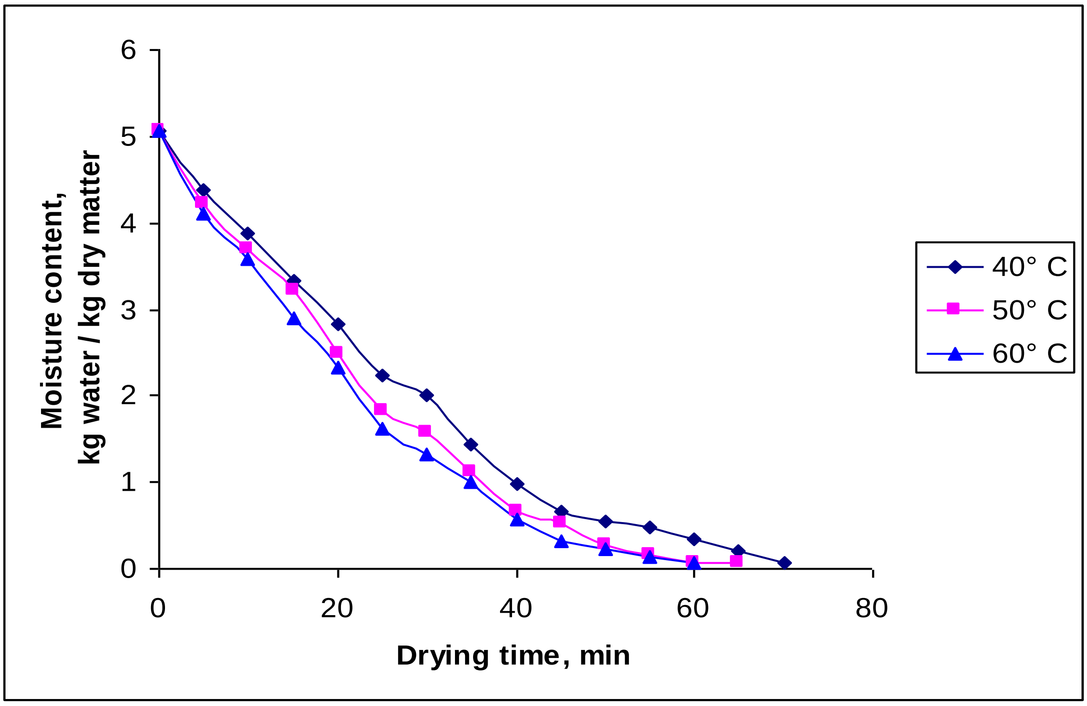

Fig.3: Moisture content vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 4 W/g power level

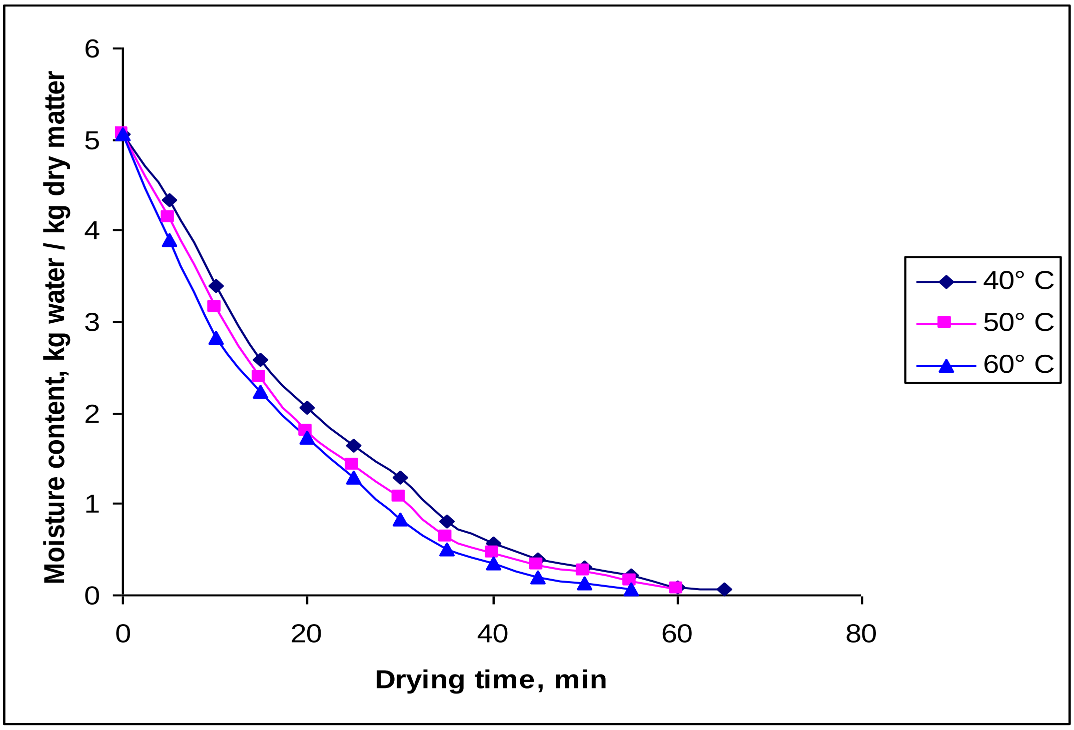

Fig.4: Moisture content vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 4 W/g power level

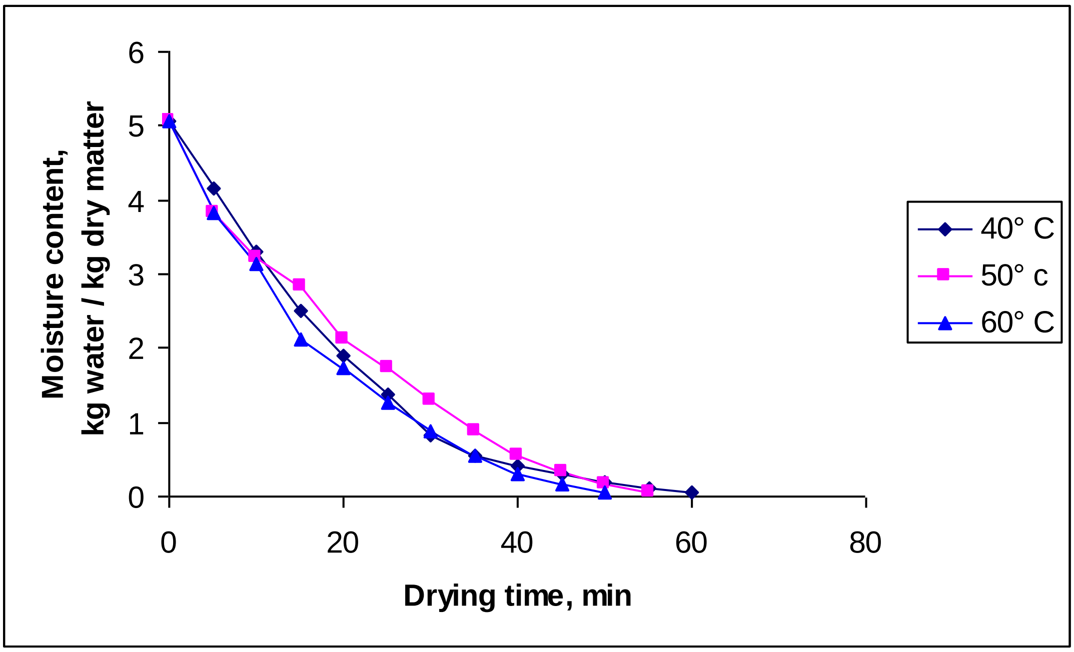

Fig.5: Moisture content vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 6 W/g power level

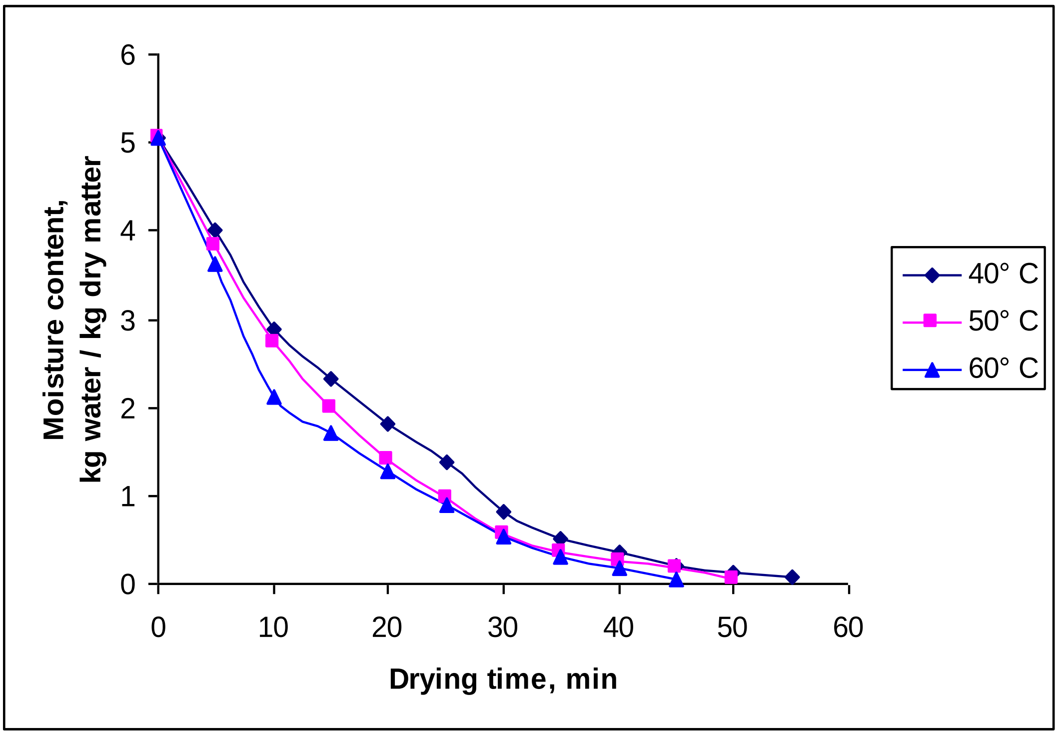

Fig.6: Moisture content vs. drying time curve of Ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 6 W/g power level

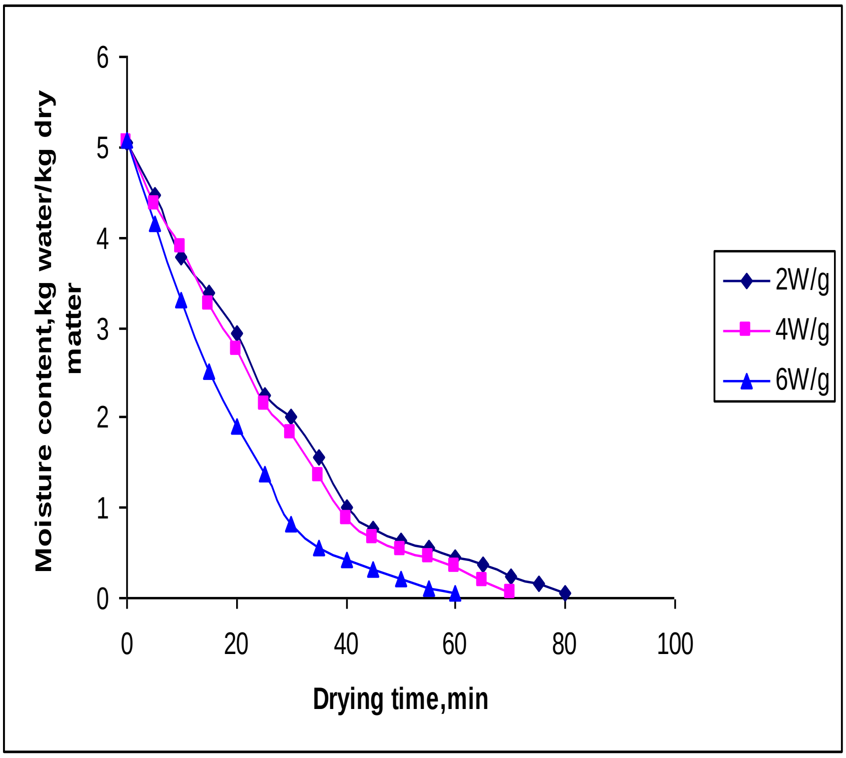

Fig.7: Moisture content vs. drying time curve of Ashwagandha roots at 40^0 C air temperature and 1.0 m/s air velocity at various power levels by convective-microwave drying

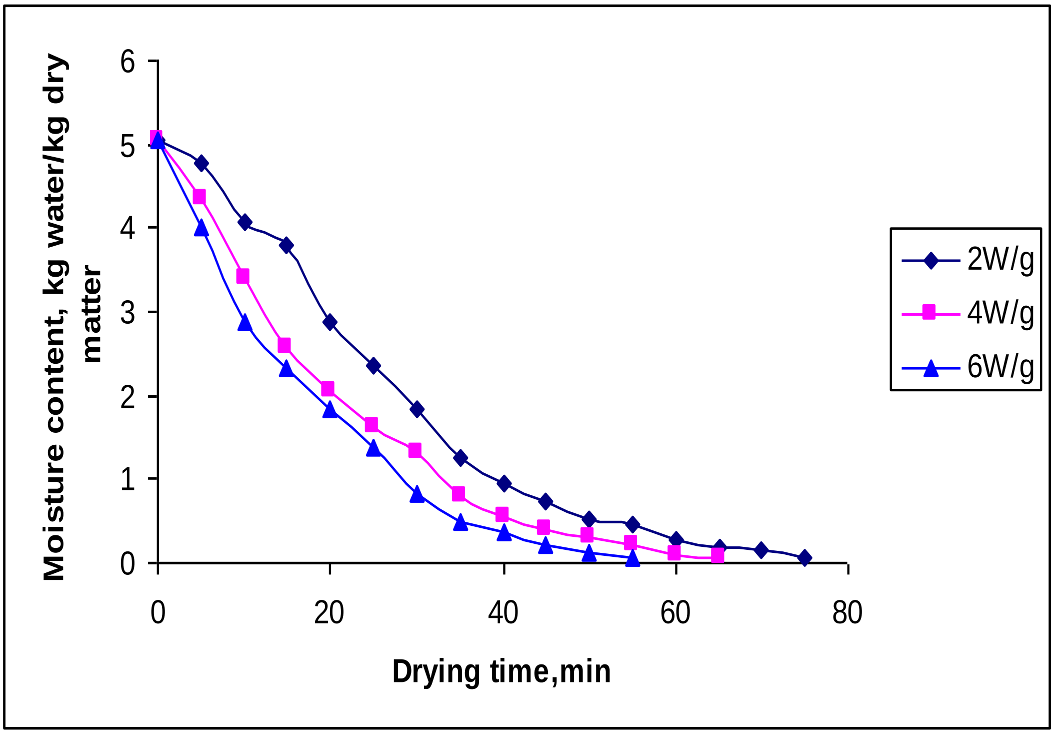

Fig.8: Moisture content vs. drying time curve of ashwagandha roots at 40^0 C air temperature and 1.5 m/s air velocity at various power levels by convective-microwave drying

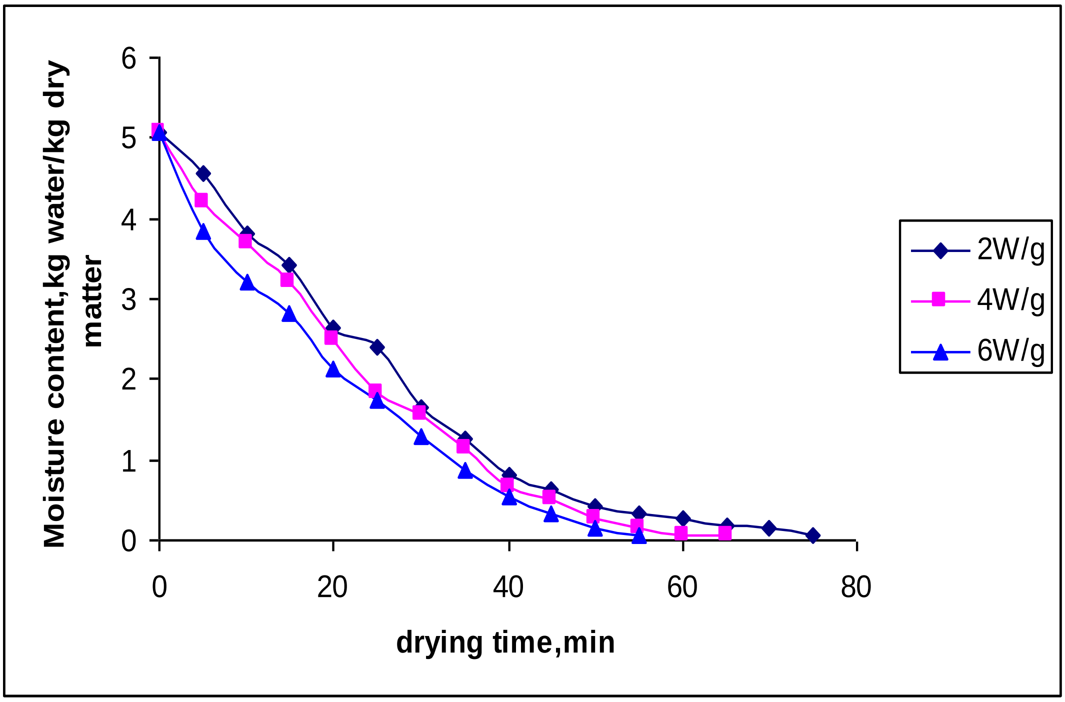

Fig.9: Moisture content vs. drying time curve of ashwagandha roots at 50^0 C air temperature and 1.0 m/s air velocity at various power levels by convective-microwave drying

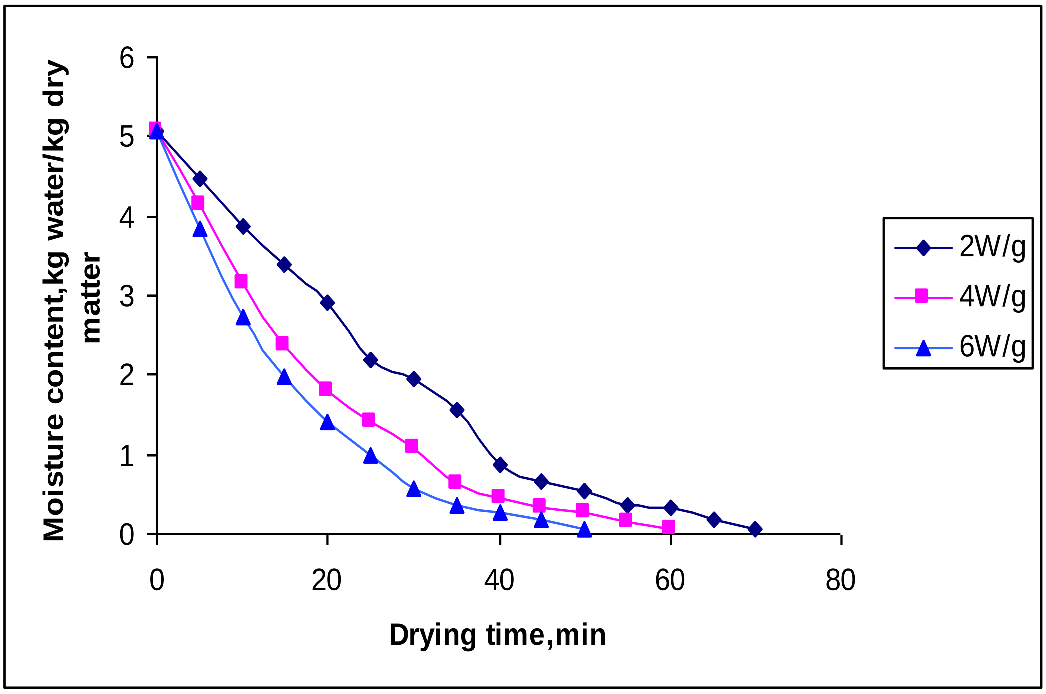

Fig.10: Moisture content vs. drying time curve of ashwagandha roots at 50^0 C air temperature and 1.5 m/s air velocity at various power levels by convective-microwave drying

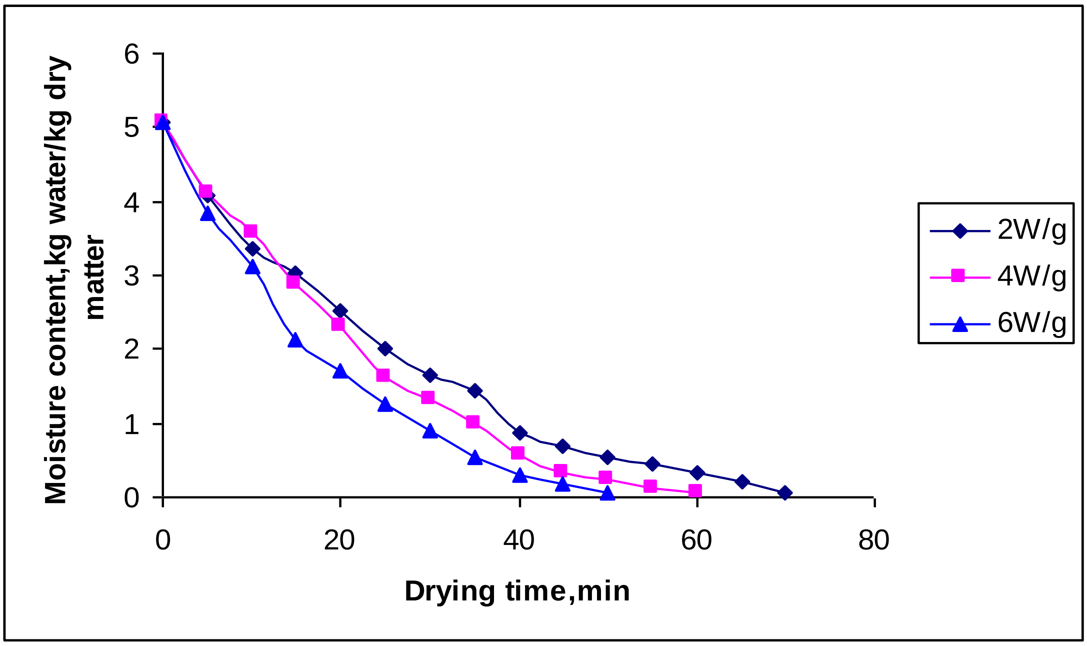

Fig.11: Moisture content vs. drying time curve of ashwagandha roots at 60^0 C air temperature and 1.0 m/s air velocity at various power levels by convective-microwave drying

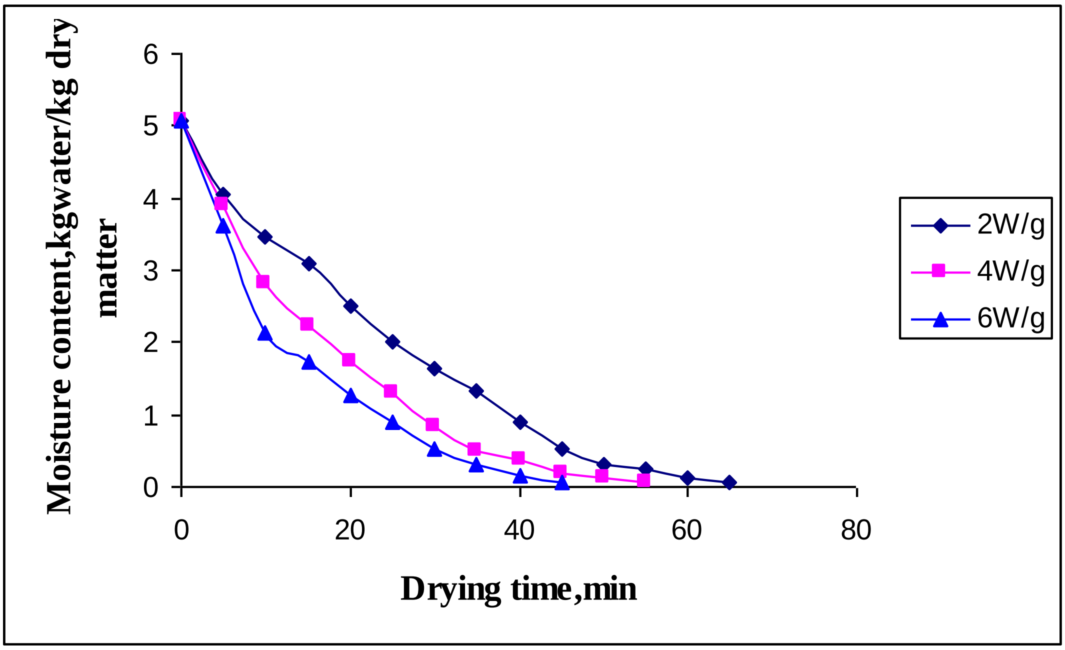

Fig.12: Moisture content vs. drying time curve of Ashwagandha roots at 60^0 C air temperature and 1.5 m/s air velocity at various power levels by convective-microwave drying

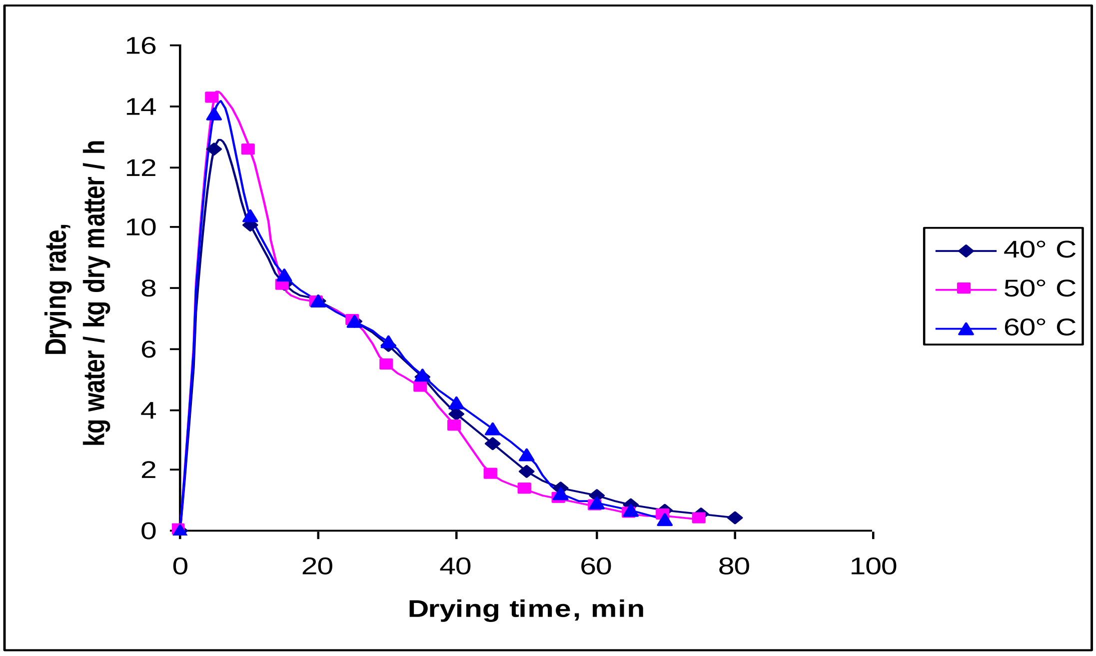

Fig.13: Drying Rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 2 W/g power level

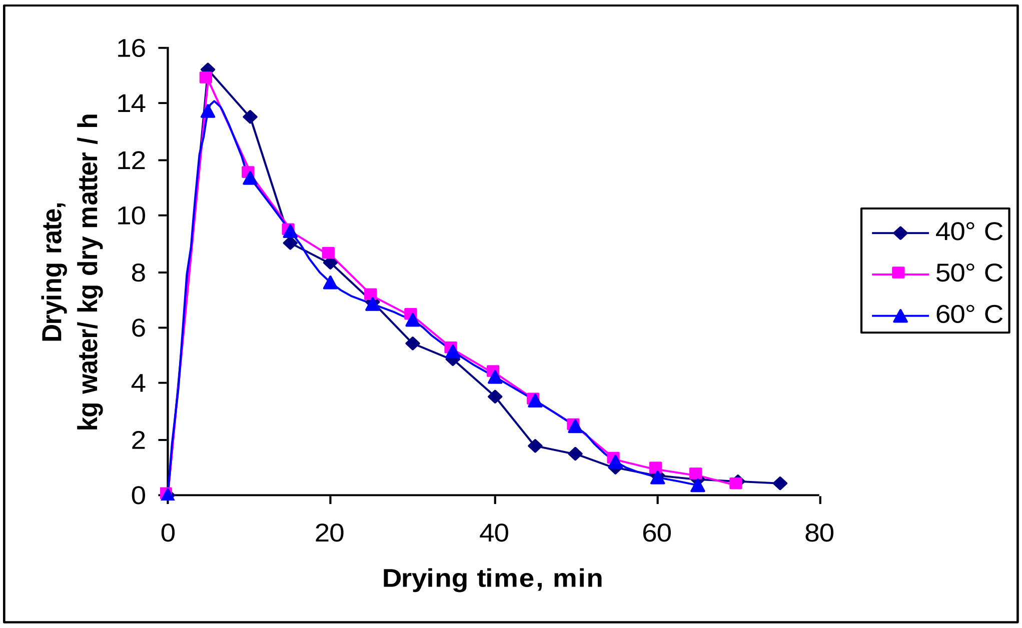

Fig.14: Drying Rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 2 W/g power level

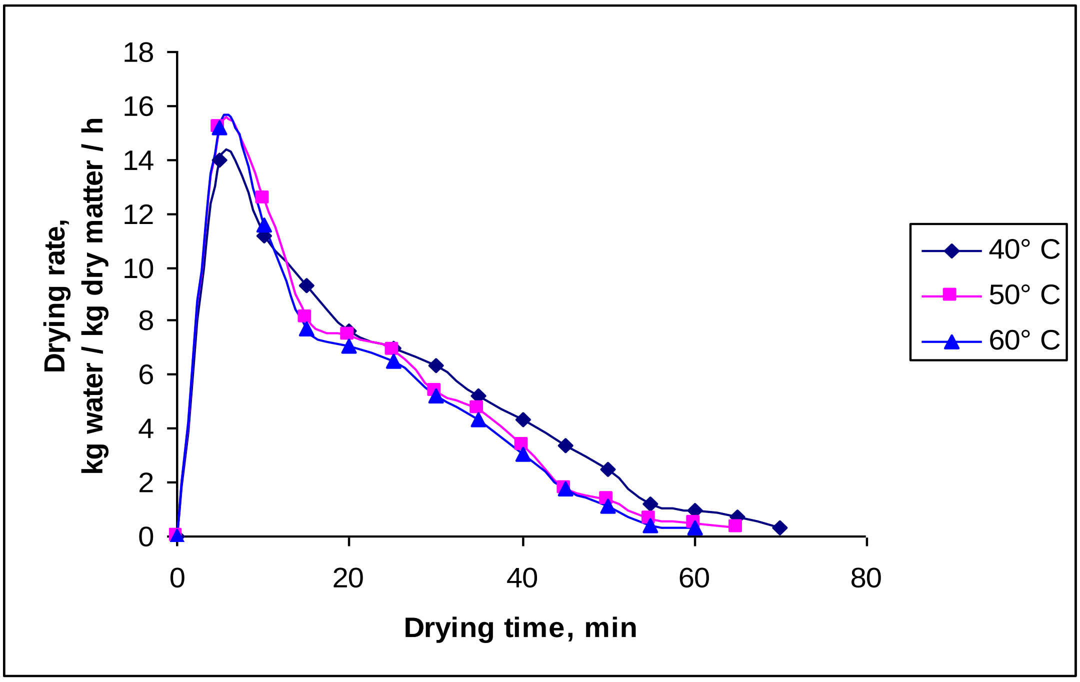

Fig.15: Drying Rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 4 W/g power level

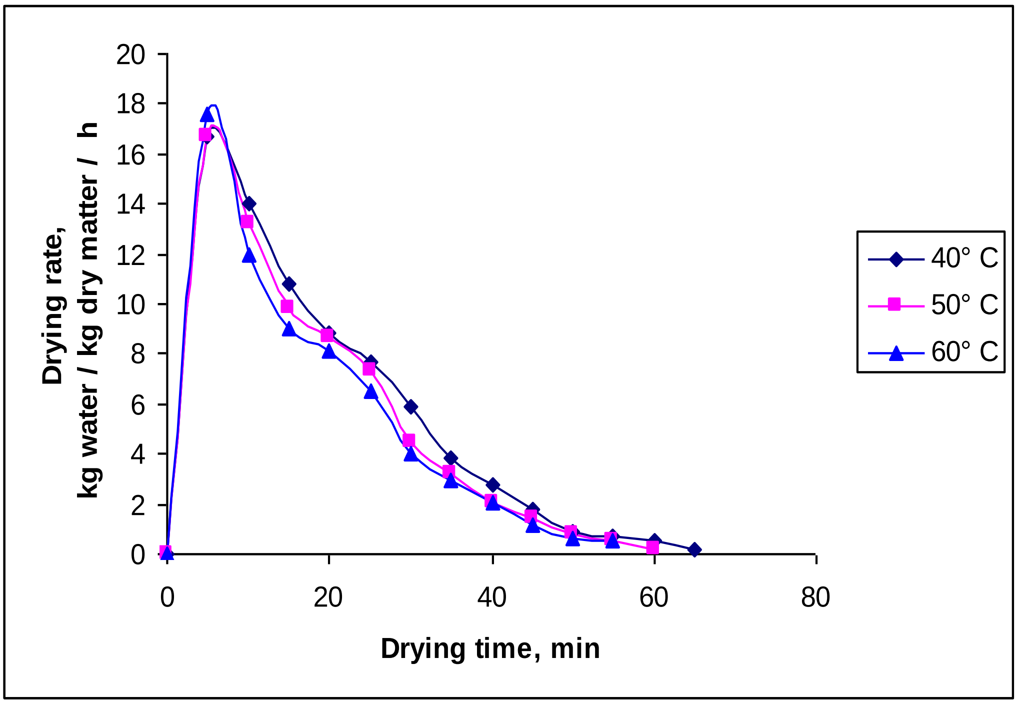

Fig.16: Drying Rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 4 W/g power level

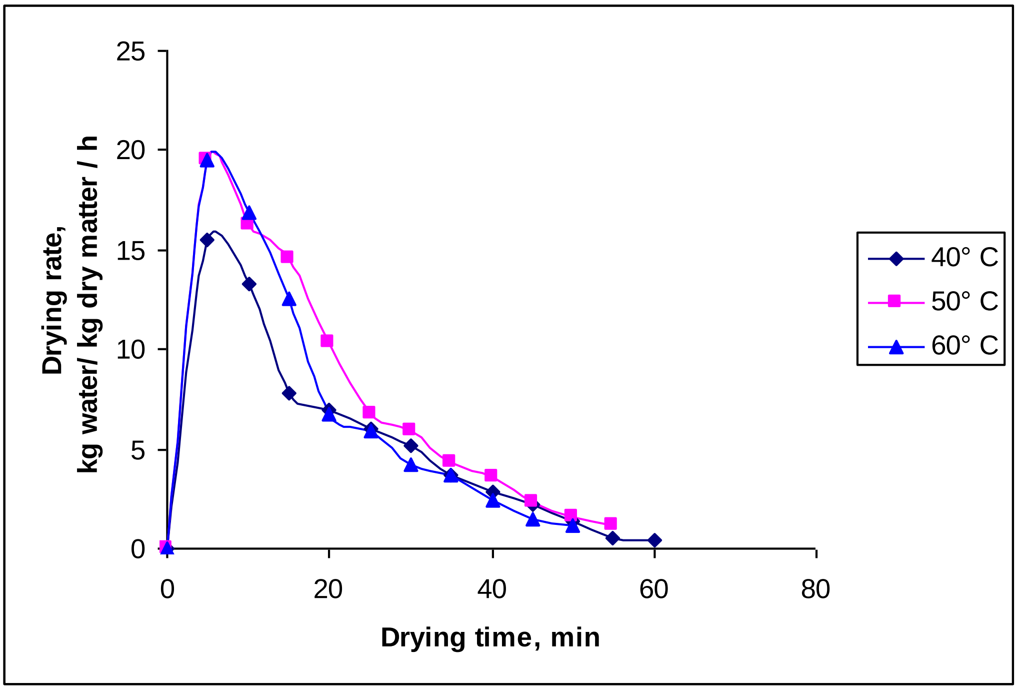

Fig.17: Drying Rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 6 W/g power level

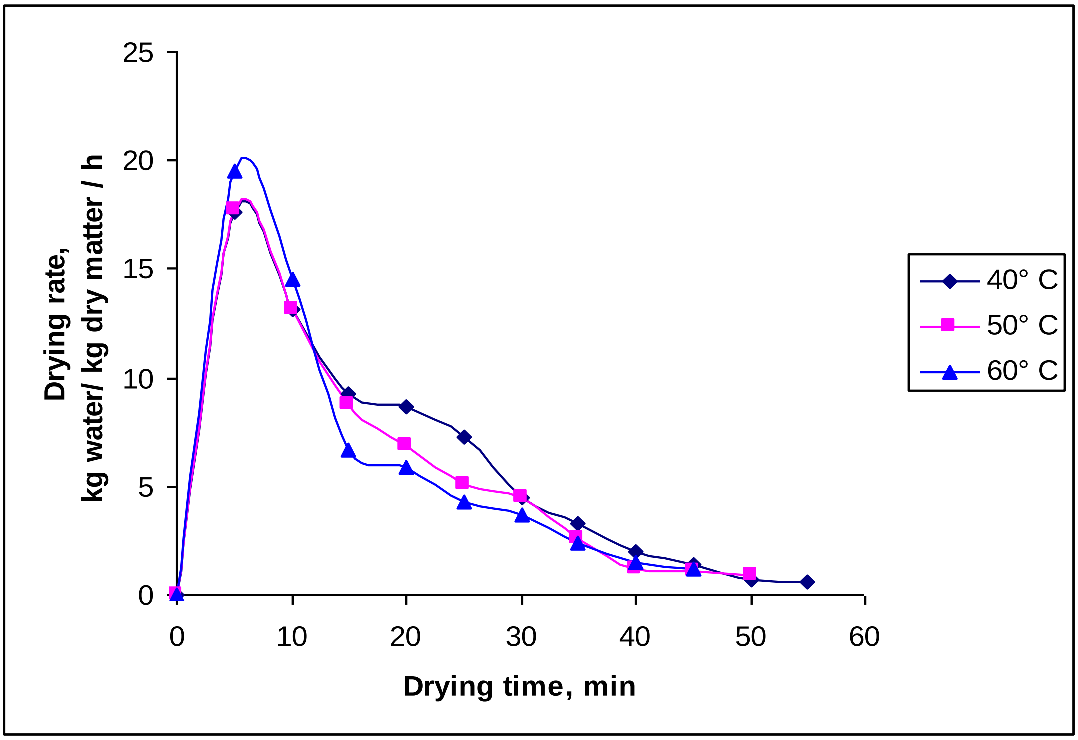

Fig.18: Drying rate vs. drying time curve of ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 6 W/g power level

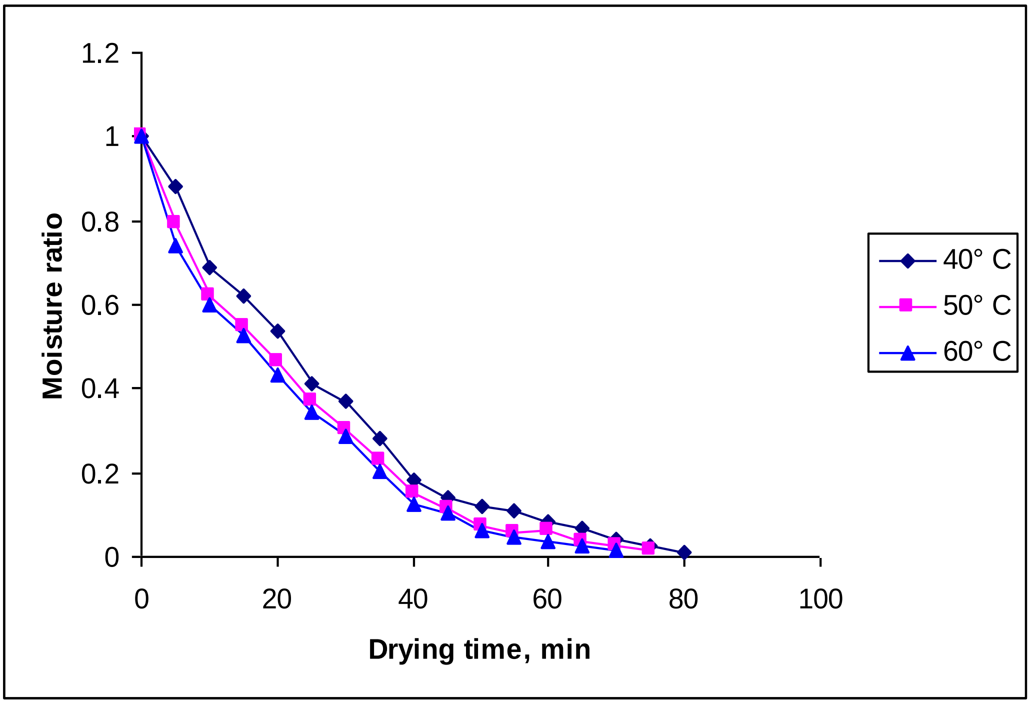

Fig.19: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 2 W/g power level

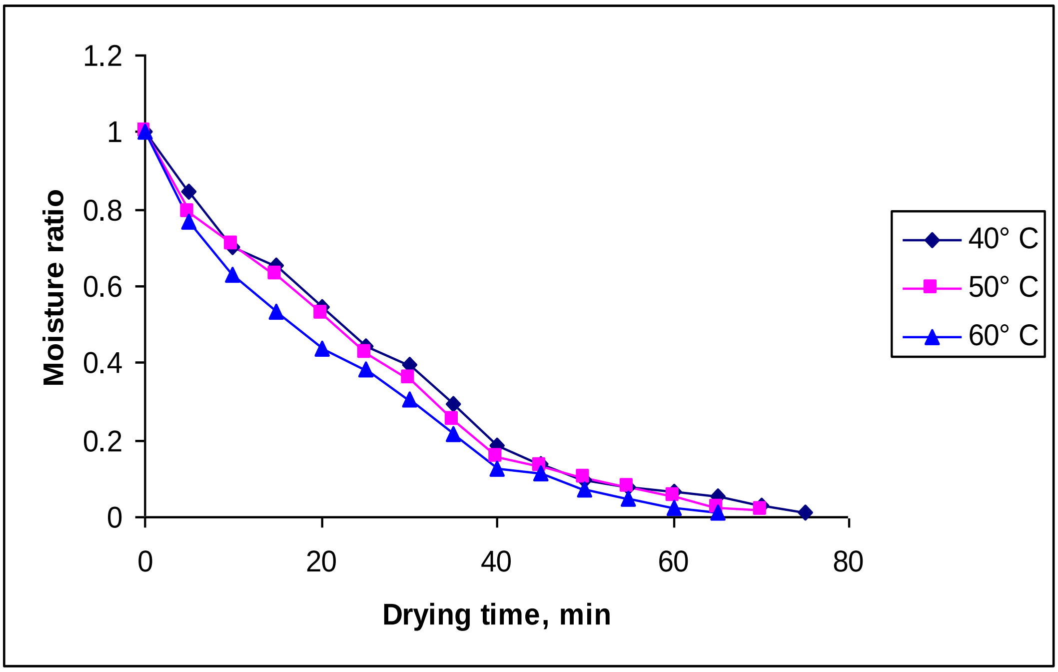

Fig.20: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 2 W/g power level

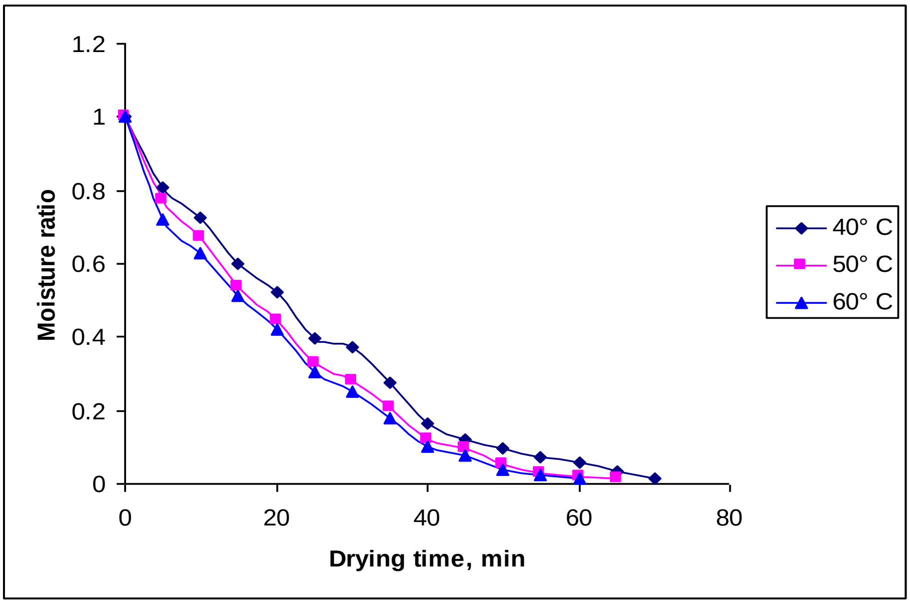

Fig.21: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 4 W/g power level

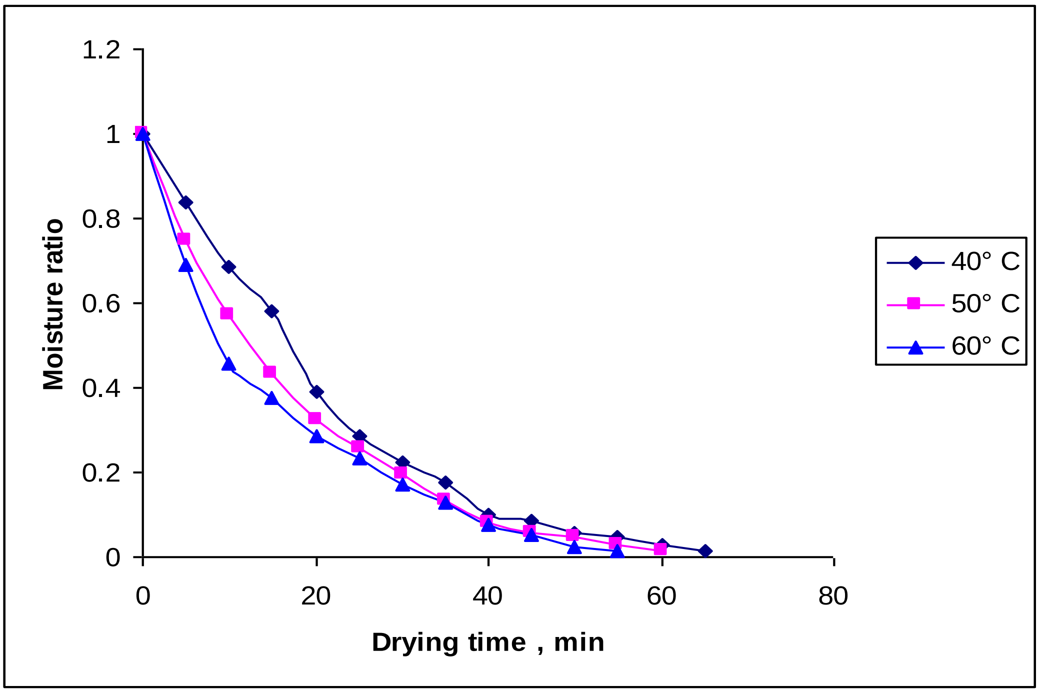

Fig.22: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 4 W/g power level

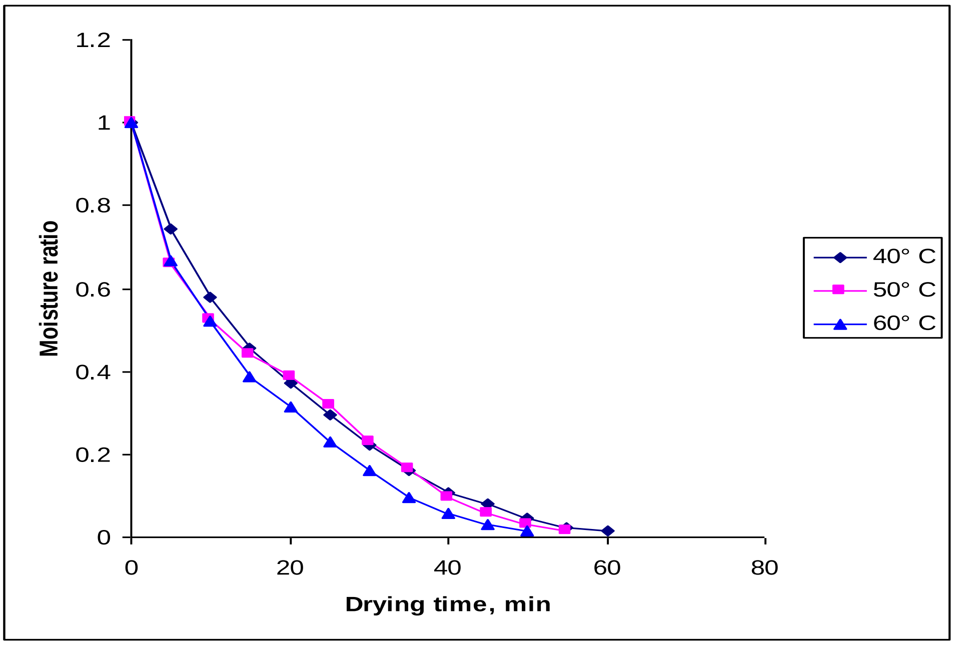

Fig.23: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.0 m/s and 6 W/g power level

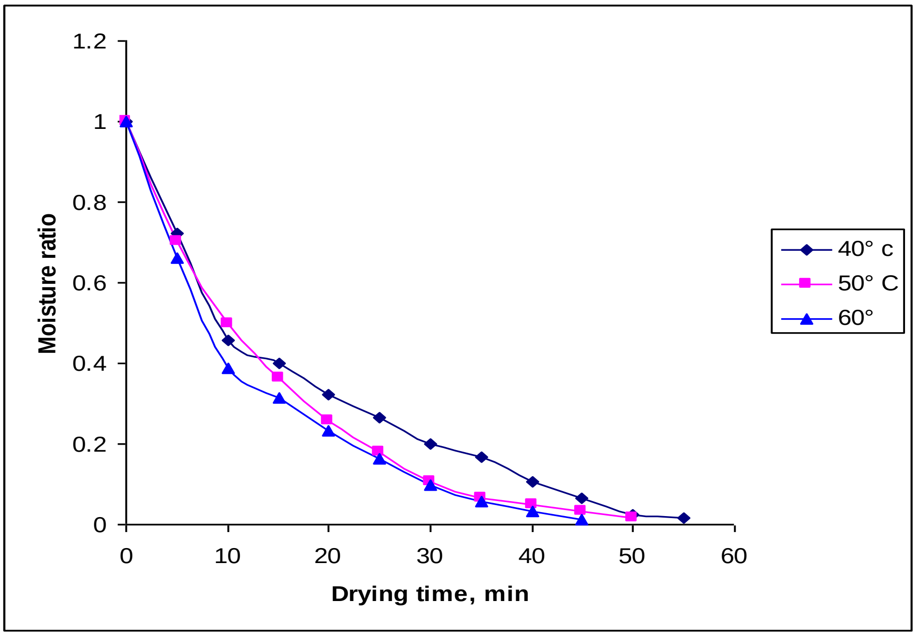

Fig.24: Moisture Ratio vs. drying time curve for ashwagandha roots at various air temperatures under convective-microwave drying condition at air velocity 1.5 m/s and 6 W/g power level

Table 1 Parameters of Page model for Convective - microwave drying of ashwagandha roots

Drying process parameters					
Power level (W/g)	**Temp.(^{0}C)**	**Air velocity (m/s)**	**k (min^{-1})**	**n**	**R^2**
2	40	1	0.065	1.102	0.996
2	40	1.5	0.051	1.157	0.993
2	50	1	0.024	1.283	0.98
2	50	1.5	0.018	1.344	0.983
2	60	1	0.064	1.184	0.99
2	60	1.5	0.053	1.263	0.996
4	40	1	0.03	1.312	0.996
4	40	1.5	0.021	1.382	0.987
4	50	1	0.064	1.2	0.986
4	50	1.5	0.058	1.256	0.994
4	60	1	0.061	1.228	0.995
4	60	1.5	0.054	1.261	0.995
6	40	1	0.063	1.264	0.994
6	40	1.5	0.058	1.243	0.993
6	50	1	0.052	1.258	0.993
6	50	1.5	0.065	1.263	0.997
6	60	1	0.059	1.261	0.991
6	60	1.5	0.066	1.264	0.997

Table 2 Rehydration ratios and total alkaloids content of ashwagandha roots dried by convective - microwave drying method

Sl.No.	**Drying process parameters**			**Quality attribute**	
	Power level (W/g)	**Temp. (°C)**	**Air velocity (m/s)**	**Rehydration ratio**	**Total alkaloids content (%)**
1	2	40	1	4.03	1.812
2	2	40	1.5	4.05	1.832
3	2	50	1	4.01	1.821
4	2	50	1.5	4.08	1.796
5	2	60	1	4.10	1.801

6	2	60	1.5	4.09	1.901
7	4	40	1	4.10	1.842
8	4	40	1.5	4.11	1.812
9	4	50	1	4.12	1.861
10	4	50	1.5	4.12	1.927
11	4	60	1	4.12	1.921
12	4	60	1.5	4.13	1.882
13	6	40	1	4.11	1.921
14	6	50	1.5	4.16	1.941
15	6	60	1	4.12	1.901
16	6	40	1.5	4.13	1.882
17	6	50	1	4.14	1.915
18	6	60	1.5	4.13	1.892

Table 3 Rehydration ratio and Total alkaloidds content of ashwagandha roots dried by sun drying method

Quality attributes		
Sr. No.	**Rehydration ratio**	**Total alkaloids content (%)**
1	2.77	1.60
2	2.78	1.54
3	2.81	15.6
4	2.67	1.62
5	2.70	1.58
6	2.71	1.48
7	2.83	1.54
8	2.86	1.58
9	2.88	1.50
10	2.70	1.44
Mean	2.76	1.54

Table 4 Design summary of convective - microwave drying of ashwagandha roots

Factor	**Name**	**Units**	**Low Actual**	**High Actual**	**Levels**
A	**Power Level**	**W/g**	**2**	**6**	**3**
B	**Temp**	**°C**	**40**	**60**	**3**
C	**Air Velocity**	**m/s**	**1**	**1.5**	**2**

Table 5 ANOVA for rehydration ratio of ashwagandha roots dried by convective -microwave drying

Source	**Sum of squares**	**Degree of freedom**	**Mean squares**	**F value**	**Prob.>F**	**Remarks**
Model	0.089644	5	0.017929	32.88635	< 0.0001	significant
A	0.050944	2	0.01694272	44.92861	< 0.0001	
B	0.012255	2	0.01966806	52.15564	< 0.0001	
C	0.026445	1	0.026445	48.50704	< 0.0001	
Error	0.002031	36	5.64E-05	-	-	

Table 6 ANOVA for total alkaloids content of ashwagandha roots dried by convective -microwave drying

Source	**Sum of squares**	**Degree of freedom**	**Mean squares**	**F value**	**Prob.>F**	**Remarks**
Model	**0.085141**	**5**	**0.017028**	**24.2827**	**< 0.0001**	**significant**
A	**0.004598**	**2**	**0.002299**	**3.278335**	**< 0.0463**	
B	**0.035926**	**2**	**0.017963**	**25.61586**	**< 0.0001**	
C	**0.044617**	**1**	**0.044617**	**63.6251**	**< 0.0001**	
Error	**0.000891**	**36**	**2.47E-05**	**-**	**-**	

Table 7 Colour changes of ashwagandha roots dried by sun drying

Parameters	**Fresh root**	**Drying Method (Sun Drying) Samples**										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Mean**
L*	43.42	37.19	37.24	37.15	37.34	37.42	37.30	37.50	37.22	36.58	37.14	37.21
a*	6.12	5.09	5.23	5.14	5.01	5.09	5.10	5.05	5.20	5.18	5.00	5.11
b*	15.51	11.30	11.21	11.61	11.52	11.65	11.20	11.32	11.15	10.12	12.11	11.32
□ E	0	7.589	7.581	7.44	7.28	7.22	7.56	7.13	7.64	8.75	7.23	7.54

Table 8 Colour changes of fresh and dried ashwagandha roots by convective -microwave drying

Parameters	**Fresh root**	**Drying method Convective cum microwave**																	
		2W/g 40°C 1.0m/s	**2W/g 40°C 1.5 m/s**	**2W/g 50°C 1.0 m/s**	**2W/g 50°C 1.5m/s**	**2W/g 60°C 1.0 m/s**	**2W/g 60°C 1.5 m/s**	**4W/g 40°C 1.0m/s**	**4W/g 40°C 1.5 m /s**	**4W/g 50°C 1.0m/s**	**4W/g 50°C 1.5m/s**	**4W/g 60°C 1.0m/s**	**4W/g 60°C 1.5m/s**	**6W/g 40°C 1.0m/s**	**6W/g 40°C 1.5m/s**	**6W/g 50°C 1.0m/s**	**6W/g 50°C 1.5m/s**	**6W/g 60°C 1.0m/s**	**6W/g 60°C 1.5m/s**
l*	43.42	37.82	37.92	36.95	37.5	37.11	37.82	37.51	37.62	37.82	37.52	37.86	37.73	37.72	37.56	37.86	38.08	38.01	37.91
a*	6.12	6.08	6.10	6.07	6.01	6.05	6.09	6.01	6.22	6.15	6.11	6.09	6.12	6.10	6.06	6.12	6.18	6.19	6.01
b*	15.51	12.84	12.92	12.72	12.82	12.79	12.93	12.22	12.35	12.92	12.72	12.83	13.01	12.56	12.83	13.11	13.65	12.91	12.63
ΔE	0	6.204	6.07	6.99	6.50	6.51	6.16	6.761	6.614	6.17	6.52	6.18	6.22	6.418	6.44	6.05	5.654	6.53	6.13