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Accelerated Dehydration of Grapes Using Hybrid Technology

Parag Zade†, Dr. Sanjay S. Lakade‡

†M.E. Heat Power, Pimpri Chinchwad College of engineering, SPPU, Maharashtra-411033, India.
‡Prof. at Mechanical Department, Pimpri Chinchwad College of engineering, SPPU, Maharashtra-411033, India.

Abstract

Dehydration is a key method to preserve foods. The market for dehydrating food is important for most of the countries worldwide. The Indian processed foods market is worth about 32% of the total food industry. Demand for high quality dehydrated fruits is increasing rapidly in Asian countries; India exported 26824.52 MT of raisins in 2015-16. Drying is most common and most energy consuming food preservation process. The long drying rate in many conventional thermal methods at relatively high temperature during the falling rate periods leads to undesirable thermal degradation of the finished products. Microwave drying offers opportunities to shorten the drying time drastically and improves the final quality of dried product. In This study optimization of drying parameters in hybrid drying of grapes was carried out. Hybrid drying includes microwave and hot air combination which will accelerate the drying rate of grapes. This research work is carried out by experimenting various drying conditions and pretreatments on grapes for accelerated drying by using response surface method in laboratory hybrid drying setup and optimized drying parameters value such as specific microwave power density and hot air temperature were used on continuous hybrid drying setup for mass production.

Keywords:*Accelerated dehydration, Response surface method (RSM), Hybrid drying, Microwaves, Hot air, grapes.*

1. Introduction

Dried grapes are known as Raisins. The word raisin is developed from Latin word "Racemus" which means "Bunch of Grapes". Scientific name of grape is "Vitus Vinifera". India has been the raisins producer since 1983 in the Maharashtra and Karnataka region [10]. India contributes 1.51% of total world production of grapes. 78% of grapes are used for fresh consumption in India while 17 to 20% grapes are used for raisins processing which is very less as compare to other countries in the world where 80% of grapes are processed to raisins, wine or juices [9].

Dehydration of grapes is energy extensive process, as water content in the grape is 75 to 83%. Drying is the process of moisture removal from moist material by using heat energy. In case of biological material such as fruits and vegetables, drying becomes a complex phenomenon which includes both heat and mass transfer. The vital challenge in the dehydration of grapes is to remove water content from 75 to 18% while maintaining the quality parameters such as colour, texture, appearance and taste [7]. Drying of grapes with only hot air takes longer time duration of 12 to 20 days or even longer depending on processing conditions. Hence feasibility of using other energy source such as microwaves was first investigated by Tulsidas in 1993 [2], [6].

Raisins mass production is carried out with the use of hot air driers. These conventional convective dryers result in slow heat transfer and thus longer drying time. For faster drying, if hot air temperature increases beyond 55^0C, browning starts due to presence of polyphenol oxidase (PPO) enzyme, which results in undesirable quality [4]. The main target in grape drying is to thin the fruit surface usually known as skin. The skin is fragmented by cracking the waxy layer present on it with the help of various pre-treatments such as dipping in the solution of ethyl oleate, NaOH, KCO_3 in water with certain predetermined percentage and time [2]. Steam blanching also used for pre-treatment as it helps in destruction of enzymatic activities and thus shown prominent results in terms of faster drying rate in some fruits [1].

Hybrid drying refers to use of two or more energy sources for drying such as hot air and microwave power. A.S. Kaseem did the comparison of drying characteristics of Thompson seedless grapes by using combined microwave oven and hot air drying and noted that moisture ratio of grapes is affected by drying methods [5]. In hybrid drying when microwave couples with material, heat is generated due to polarization and ionic conduction effects on water molecules present inside which results in volumetric heat generation and thus water evaporation [8]. The next important step to immediately remove this water vapour coming out of product, hence hot air is blown over the product and thus the process can also be termed as microwave assisted convective drying.
The objectives of this study were to investigate (1) the effect of microwave power and hot air temperature on the drying time for fresh grapes and (2) to optimize these parameters based on quality of produced Raisins. This study work also aims (3) to construct a

continuous conveyor type microwave convective drier which will serve the need of small farmers in India.

2. Materials and Methods

2.1 Materials

Fresh grapes were directly purchased from local market of Belgaum, Karnataka (India) and big cluster fragmented in small bunches, each carrying 2 to 8 grapes. Before starting drying experiments, grapes were pretreated with solution of 0.5% NaOH and 2.5% ethyl oleate by weight in the water by dipping at 80^{0}C for 30 sec. More dipping than 30 sec may results in peeling off of the grape skin and thus sticky and undesirable texture of produced raisins. Treated grapes were kept on perforated tray after weighing and then introduced to microwave assisted convective drier.

2.2 Hybrid drying

Grapes drying experimentation was carried out in a laboratory hybrid drier facility present with Enerzi Microwave systems Pvt. Ltd., Belgaum, Karnataka (India). Grapes were converted to raisins by removing moisture content from 75 to 18%. The schematic diagram and actual picture of the hybrid drier set up is shown in fig 1. Hybrid drier had been developed by coupling a hot air blower to microwave cavity (Drying chamber). Magnetron of 800W (2450 MHz frequency) with step value of 90W is used to shower microwaves on rotating tray. The microwave cavity had dimensions of 245(L)×255(W)×235(H) mm. Power output from the generator was displayed by control panel. Turntable is used to rotate grapes tray so that uniform heating may be assured. The control panel had provision to regulate microwave power, hot air temperature and its velocity. Wattmeter is also provided to record energy consumption in drying process. A hole is made at bottom of the microwave cavity to feed hot air through SS pipe which was coupled to air blower followed by heating coil at its other end. Another hole is made at top with the provision of regulating valve to exhaust inside hot air.

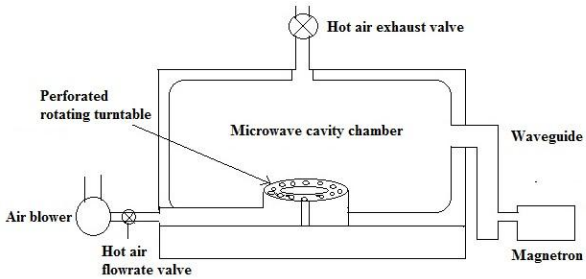
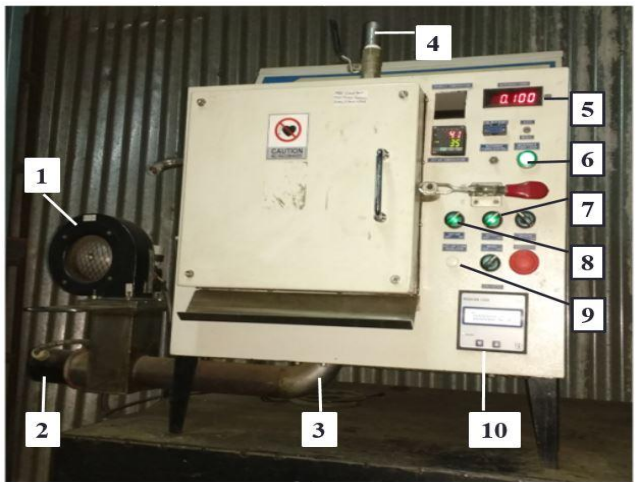


Fig.1 Schematic of Laboratory scale model of hybrid drying setup



1	Air blower	6	MW power switch
2	Heating coil	7	Turntable switch
3	Hot air inlet	8	Hot air switch
4	Hot air outlet	9	Air flowrate adjusting knob
5	Microwave (MW) power indicator	10	Wattmeter

Fig.2 Laboratory scale model of hybrid drying setup.

Many experiments were carried out to optimize the drying process with random runs which includes optimization of pretreatment and drying parameters viz. specific microwave power density and hot air temperature.

3. Experimentation and Methodology

Dehydration experiments were carried out as per central composite design in response surface method by using statistical software Minitab 17. Prior to optimization of drying parameters, pretreatment was optimized first by doing experiments with different chemicals but with same operating conditions.

3.1 Pretreatment

Different pretreatments were done on similar grape samples by fixing microwave power, hot air temperature and air velocity and its effect on drying time was investigated. Pretreatments are necessary to produce fine cracks on the skin of the grapes so that only moisture will come out and not the sugar compound present inside the grape. Proper pretreatment ensures proper quality in terms of texture and color of the raisins. Pretreatment method is given as:

1) Fresh grapes were purchased directly from market and its big clusters fragmented into small bunch of grapes where each bunch consists of 2 to 8 grapes. The grapes weight then noted.
2) Dipping in 0.5% NaOH and 2% ethyl oleate (EO) is used as pretreatment method. For 5 liters of water 25 gm NaOH and 100 ml Ethyl Oleate was added and the solution is heated up to 80^{0}C. Grapes were then dipped in the solution for 30 sec and then washed with tap water.

3) It is observed that with the mentioned pretreatment, waxy layer on the grape fruit became thin and fragmented and appearance of texture resembled to market Raisins.
4) Pretreated grapes kept in perforated plastic tray of size 290×235×30 with grape layer of 10 mm. Each tray loaded with grapes whereas weight of each tray taken before loading grapes and noted. Label consists of Tray weight without grapes and tray number attached to each tray. (E.g. If total weight is 812 gm then 700 gm is grapes weight and 112gm is tray weight).

3.2 Experimentation

Experiments are carried out with the use of response surface method in Minitab 17 software. Two variables are selected for variation to check its effect on drying time. All experimental trials taken on laboratory scale model and then optimized values used in continuous conveyor type microwave assisted convective dryer facility present at Enerzi Microwave Systems Pvt. Ltd., Belgaum, Karnataka (India). The instruments used in trials and final run are temperature sensor gun and electronic weighing machine. For trial runs specific microwave power density varied from 0.15 W/g to 0.35W/g as higher microwave power density is harmful for grapes as temperature of grapes increases. Increased temperature of grapes results in undesirable color and sensory quality (Gokhan). Temperature range of 35^{0}C to 55^{0}C is used to optimize convective hot air temperature.

3.3 Continuous Conveyor Type Hybrid Drying Setup

1) Experimental set up as shown in figure 3 consists of 5 magnetrons which were attached to horn type waveguides, 3 blowers, drying chamber, continuous conveying perforated belt and power controller.
2) Each magnetron is of capacity 800 W, 2450 MHz is mounted on top of drying chamber followed by horn type waveguide which were showered the microwaves into the drying chamber as shown in figure 2. Each magnetron provided with blower for cooling its coil to keep its temperature within working range.
3) 3 blowers are provided from bottom of drying chamber which supplies hot air through electrical heater. Each blower air temperature may be varied through controller as per need.
4) Continuous conveyor belt is provided to feed in and feed out the grapes trays. Belt is perforated to allow hot air to pass from blower to surface of grapes. Belt speed is kept as 150 mm/min.

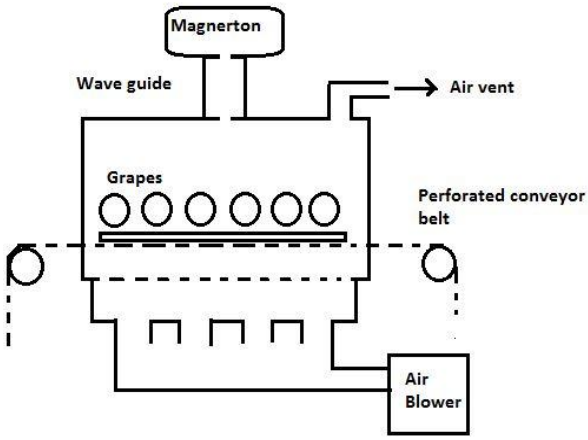


Fig.3 Schematic of continuous hybrid drying set up

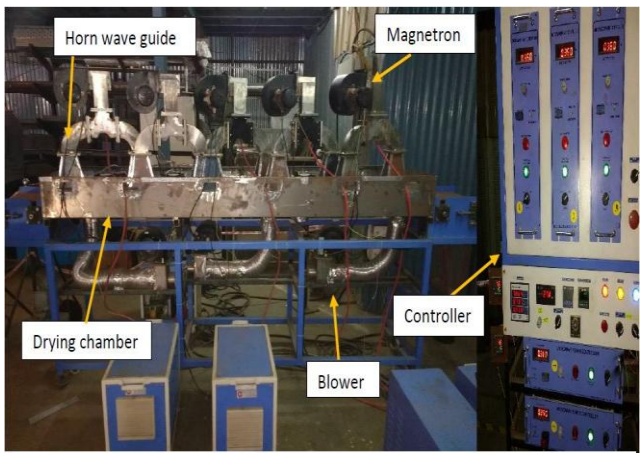


Fig.4 Actual picture of continuous hybrid drying setup.

3.4 Procedure

1) Power on the supply to setup and controller.
2) The blower hot air temperature adjusted at 600C and started to feed trays one by one inside the drying chamber. Grapes were preheated up to 2 hours at same condition and after preheating weight reading of each tray had been noted.
3) Adjusted the blower hot air temperature at 450C. Turned on Magnetron power one by one as tray number 1 reach down to waveguide of corresponding magnetron. Power wattage adjusted to each magnetron as per specific power density of 0.25 W/gm.
4) Continued the process for 4 hours and noted weight readings of each tray after every hour.
5) After 6 hours, the microwave power of magnetron switched off, one by one as tray 1 reach down to corresponding waveguide.
6) For post heating, hot air temperature kept at 40^{0}C and allowed to pass grapes for one hour on conveyor. Final weight reading of each tray was noted.

3.5 Quality Analysis

Quality in terms of texture and color were studied as quality parameters of produced raisins. Properties like acidity, brix, water activity, moisture content were compared to market raisins through National Agriculture and Food Analysis Research Institute (NAFARI), Pune.
Texture of the raisins mainly depends on fine fragmentation during pretreatment while color analysis is carried out by measurement of ΔE values by using spectrophotometer.

Color Analysis

Color of the raisins is one of the most important parameter in quality and plays major role in marketing as appearance of the product is important for consumers. To determine color of the samples, spectrophotometer is used. Color values are determined in terms of a (redness/greenness), b (yellowness/blueness), L (whiteness/darkness) and color difference (ΔE) [12]. Equation 1 is used for color difference calculation [3].

$$\Delta E = \sqrt{(L-L^*)^2 + (a-a^*)^2 + (b-b^*)^2} \quad (1)$$

Where ΔE indicates degree of color change of a sample when compared to an ideal sample which have color values L*, a* and b*. Ideal sample taken as reference as per ICAR National Research Institute of Grapes, Manjri farm, Pune, Maharashtra (India).

3.6 Data Analysis and Optimization Technique

Response surface method (RSM) was used to evaluate the contribution of two drying parameters viz. specific microwave power density and hot air temperature to responses drying time and color analysis under study. Response surface method (RSM) is statistical method used in design of experiment for multivariate problems. Advantage of RSM is that it gives acceptable results with less number of experiments and states the relationship between responses and variable inputs [12].
Following second order polynomial equation was used for experimentation data analysis to study relationship between response surface to coded variables.

$$y = \beta_{k0} + \sum_{i=1}^{k} \beta_{ki} \cdot Xi + \sum_{i=1}^{k} \beta ii \cdot Xi^2 + \sum_{i \neq j=1}^{k} \beta_{kij} \cdot Xi \cdot Xj + E \quad (2)$$

Where, 'y' is output response, 'k' is number of variables in the experiment, 'Xis' are process variables in coded format and 'E' is random error. Higher value of regression coefficient β, indicate the more importance of variable affecting the process and vice versa [12]. Analysis of variance (ANOVA) and regression analysis were conducted by using a statistical software Minitab, version 17, also graphs of response obtained from the software.

4. Result and Discussion

4.1 Drying Parameters Optimization

Previous studies summarized that specific microwave power density higher than 0.25W/g is not suitable for acceptable raisins quality as center temperature of grapes rose over 850C and 1000C when power levels kept at 0.5W/g and 1W/g respectively [1]. Thus, variation range from 0.15W/g to 0.35W/g with step value of 0.05 is taken under experimentation and observed that 0.25W/g is optimized specific microwave power density. This agrees with previous work of Tulsidas [2] and Gokhan Bingol [1].

In addition to specific microwave power density, optimization of convective hot air temperature is also carried out with fixed velocity of 0.9m/s. It should be noted from our experiments that higher microwave power density as 0.3W/g can also be used with lower hot air temperature but such combination results in more energy consumption. To study the effect of hot air temperature on drying kinetics, hot air temperature variation ranges from 35^{0}C to 55^{0}C with step value of 5 had been selected. Higher temperature of air contributes in rising of temperature of product which is unsafe for grapes. The optimized combination is found as specific microwave power density of 0.25W/g coupled with 45^{0}C hot air temperature.

4.2Pretreatment

Various pretreatments were carried out to check the fragmentation of grape skin as it directly related to final texture of raisins. 3% ethyl oleate and 2.5% potassium carbonate at 40^{0}C for 3 min treatment was assume as best as it shown better results in shade drying of grapes, but for microwave drying with the aim of reduced drying time, this treatment was ineffective. This is in agreement with Gokhan who noted untreated grapes and above said pretreated grapes shown same drying behavior [1]. However, we found 0.5% NaOH and 2.5% ethyl oleate at 80^{0}C for 30 sec is best pretreatment for hybrid drying of microwave and hot air combination.

4.3 Drying Time

Experiments were carried out to minimize drying time with optimum quality. It is observed that 0.25W/g specific microwave power density and 450C hot air temperature is optimum combination. Experiment results are as per graph which shows reduction in moisture content with respect to time. Preheating and post heating methodology is being same as discussed earlier.

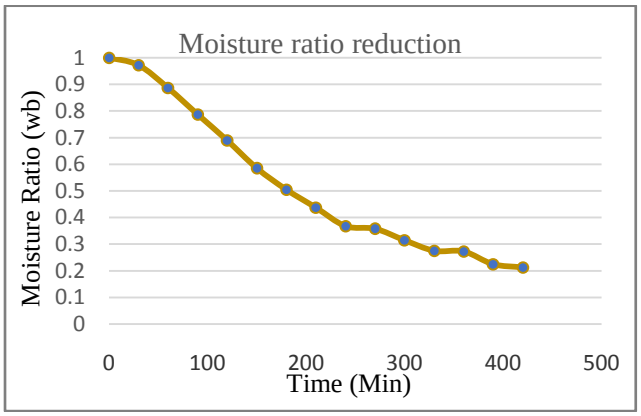


Fig.5 Relation of moisture ratio with drying time for hybrid drying.

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4.4 Color Characteristics of Raisins

Changes in color of samples according to different combinations of drying parameters were determined in terms of ΔE values for produced raisins. Spectrophotometer [11] was used to determine L, a, and b values and from these values ΔE values were calculated with use of formula discussed earlier. L, a, b and ΔE values of standard sample was 49.12, 14.97, 59.94, 5.34 and color value for optimum combination of 0.25W/g specific microwave power density and 450C hot air temperature was found to be 46.67, 20.49, 59.79, and 6.56. Change in color can be significantly seen for different combinations as shown in table. Higher specific microwave power density considerably changes color to dark brown as it contributes in temperature rise of grapes during drying.

Table 1 Color values for different hybrid drying conditions.

Drying Parameters		ΔE Values
Sp. MW Power Density	Hot Air Temp.	
0.15	55	16.68
0.25	35	6.62
0.25	45	6.56
0.35	55	51.94
0.25	55	8.42
0.35	45	48.34
0.15	45	14.52
0.15	35	7.35
0.35	35	50.87

For lower Specific microwave power density and higher hot air temperature combination, color values had been seen higher, this may be due to prolonged drying time required. For higher microwave power and moderate temperature combination drying time will be lesser but browning happens due to elevated temperature of product during drying.

4.4 Sample Analysis

Produced raisins were given to National Agriculture and Food Analysis Research Institute (NAFARI), Pune for its analysis. Test report is as given in table 2. Comparative analysis for produced raisins and readily available market raisins was also carried out for two important factors such as total sugar as sucrose and moisture. Close resemblance was found between market sample and hybrid dried sample, which confirms feasibility of the produced raisins to market in terms of quality.

Table 2 Test report from NAFARI for hybrid dried raisins

Parameters	Results	Range	Units	Test Methods
pH	4.03	3.8 - 4.1	--	IS 2860:2008
Acidity	1.94	1.5 - 2.2	g/100 g	IS 2860:2008
SO_2	10.44	≤ 1500	ppm	Ranganna
Brix	77.19	70 -80	g/100 g	AOAC 932.12
Water Activity	0.6	0.5 – 0.6	--	Water activity meter
Total sugar as sucrose	73.91	≥ 70.6	g/100 g	AOAC 923.09
Moisture	10.8	≤ 18	g/100 g	AOAC 920.151

Table 2 Test report from NAFARI for market raisins

Parameters	Results	Range	Units	Test Methods
Total sugar as sucrose	82.77	≥ 70.6	g/100g	AOAC 923.09
Moisture	10.35	≤ 18	g/100g	AOAC 920.151

It is observed that moisture content is nearly same when hybrid dried raisins are compared with market sample. Total sugar content as sucrose present in both samples are different, this may be as it depends on harvesting. SO_2 detected in hybrid dried sample may be from pest control chemicals used during harvesting. Water activity represents the ratio of vapor pressure of the raisins to the vapor pressure of pure water under the same condition. If this ratio is multiplied by 100 we obtain equilibrium relative humidity (ERH) that the raisins will produce if enclosed with air in a sealed container at constant temperature. Water activity significance is to predict growth of bacteria, yeast and molds. Acidity and brix range provided as per California board of raisins marketing [13].

Conclusions

Hybrid dehydration of grapes was studied by applying response surface method (RSM) for design of experiments. Drying experiments were performed on laboratory hybrid drying setup by varying two process parameters such as specific microwave power density and hot air temperature in range of 0.15W/g to 0.35W/g and 35^{0}C to 55^{0}C respectively. It was found that 0.25W/g MW power density and 45^{0}C hot air temperature is safe and best suitable for faster drying and optimum quality. Optimized parameters were used as process parameters for mass production of raisins and same results were assured. For quality check and feasibility to market, dried samples were analyzed

through National Agriculture and Food Analysis Research Institute (NAFARI), Pune, Maharashtra (India) and results were assured with acceptable desired quality.

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