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Drying kinetics for vegetable seeds with Zeolite beads

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ABSTRACT

Drying seeds and maintaining low seed moisture content is critical in hot and humid climatic conditions with conventional drying method. In this study Zeolite beads which are inert adsorbent materials have been used for drying tomato and onion seeds. Response Surface Methodology was employed to optimize the parameters of drying for seeds of tomato cv. Pusa Ruby and onion cv. Nasik Dark Red in Central Composite Rotatable Design (CCRD). The effect of initial moisture content, residence time and seed-bead ratio on final moisture content, germination percentage and vigour was determined. Five levels of initial moisture content (8.6 to 15.4 %db), residence time (1.3, 4, 8, 12, 14.7 h) and seed-bead ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17) were used for the experiment. Second degree polynomial models were found suitable for each response, viz. final moisture content germination percentage and vigour. The desirability index technique was used to predict the ideal drying condition. At the optimum values of 11.84% initial moisture condition, 10.8 h residence time and 1:0.5 seed-bead ratio, final moisture was 3.94%, germination percentage was 76.99% and high vigour for tomato seeds. Similarly, at optimum values of 13.62% initial moisture condition, 6.52 h residence time and 1:0.62 seed-bead ratio, final moisture was 5.55%, germination percentage was 71.08% and high vigour for onion seeds.

Key words: Moisture content, Onion seeds, Tomato seeds, Zeolite beads

India is next only to China in vegetable production with an annual production of 162.2 million tonnes from 9.2 million ha having a share of 14% to the world production (Anonymous 2015). Vegetables play a major role for nutritional and economic security, especially in Indian context, where major part of population is vegetarian. Our demand of vegetables will be 225 million tonnes by 2020 and 350 million tonnes by 2030 (Anonymous 2011). Among all cultivated vegetables; onion and tomato are important vegetables as they are the most vital ingredients in Indian food, and shortages can cause price increases and social unrest. The major challenge is therefore to make quality seed available at the time of sowing.

Various methods of seed drying have been adopted ranging from traditional; sun drying to sophisticated drying systems like the microchip controlled system. Most of these methods use air as drying media and its temperature as driving factor for rate of drying. The higher temperatures used for drying makes the process faster but are often a threat to seed quality. The quality of high value low volume seed is very sensitive to high drying temperatures (Javaregowda *et al.* 1990).Sun drying is time and labour intensive and is also weather dependent. It also affects seed quality traits adversely (Rao *et al.* 2006).The important factors affecting the drying process are initial seed moisture content, drying air temperature, relative humidity and air velocity(Amer *et al.* 2003).Among high value, low volume seeds, the tomato and onion seeds are critical and sensitive to high temperature drying, which induces drastic 'heat injury'. This heat injury reduces germination, vigour and shelf life of seeds considerably. Alternatively desiccant drying is one option. Silica gel, Betonite and some salts like calcium sulphate, calcium chloride, sodium chloride have been used for drying of seed. It has been found effective in reducing moisture content of seed (Xiorong *et al.* 1998, Zheng *et al.* 2001, Hu *et al.* 2002, Zeng *et al.* 2006). Normally desiccant drying is very slow process. Also though some desiccants like silica gel can be regenerated by heating,there is loss of water holding capacity of silica gel due to polymerization after repeated heating. These methods therefore make a non-viable option.

Recently, Zeolite beads have been developed which can be used as drying desiccant (Asbrouckand Taridno 2009). Zeolite beads have a higher affinity for water than silica gel even at low humidity levels. Also, there is no loss of water holding capacity of drying beads after repeated regeneration process. This is in contrast to silica gel, which loses effectiveness with repeated regeneration. The Zeolite beads have an extremely high capacity to adsorb water, even at very low air humidity, making them optimal drying material. The adsorption process is fully reversible and of purely physical nature. The beads can be regenerated

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indefinitely by heating to elevated temperature. Drying beads are modified ceramic materials (aluminum silicates and zeolite) that specifically absorb water molecules and hold them very tightly in their microscopic pores. These beads are available in 5 and 8 mm sizes. These beads are non-toxic and essentially inert, like ceramics.

MATERIALS AND METHODS

The popular variety of tomato and onion seeds, cv. Pusa Ruby and Nasik Dark Red, respectively were procured from the local market.The initial moisture content of tomato and onion seeds was 8.7% and 11.2% (db), respectively. The samples were cleaned and graded using pneumatic separator and air screen machine.

The samples were either dried or sprinkled with predetermined quantity of water to bring the moisture levels in the range of 9 to 15.5% (db) as per requirement of design of experiment (9, 10, 12, 14 and 15.5%). The water sprinkled samples were thoroughly mixed by hand, packed in airtight polythene bags and kept for 48 h under refrigerated condition (at about 15°C) for moisture equilibration. The bag was shaken at regular intervals for uniform distribution of moisture inside the sample. Samples were kept in a tray dryer at 40ºC until the desired lower moisture content was attained. Moisture content was determined using standard hot air oven method (ISTA 1993).

The seed quality i.e. germination and vigour evaluation of samples was carried out. Fifty hundred seeds in three replications were subjected for germination test in top paper method (ISTA 1993). The samples were kept in the germinator for 14 days at temperature of 20ºC. The number of normal and abnormal seedlings and dead seeds were recorded. The germination percentage was expressed based on normal seedlings. Vigour index was calculated by multiplying standard germination percentage by seedling dry weight in mg (Abdul-Baki and Anderson 1973). Ten normal seedlings of each replication were drawn at random and were subjected to reckon vigour index (VI). The seedlings were dried at 104ºC in oven for 8 h to get seedling dry weight.

The central composite rotatable design (CCRD) experiment with three independent variables, viz. initial moisture content (IMC), seed-bead ratio (SBR) and residence time (RT) were employed for optimization. Original values of each variable were coded for five levels as -1.682, -1, 0, +1 and +1.682. Three important seed quality parameters, viz. final moisture content (FMC), germination percentage (GP) and vigour index (VI) were considered as dependent parameters (Table 1). Response surface regression was performed for analyzing the spectral properties of the fit surface and calculating the ridge of optimum response. In the following case, three mathematical functions of *f* areas summed to exist for *Y*:

Y= *f* (seed-bead ratio, residence time and initial moisture content)

A second-degree polynomial equation in the following form can be used to approximate the function fk.

Table 1 Process variables and their levels

Process variables	Code	-1.682	-1	0	1	1.682
		Actual Levels				
Seed-bead ratio	X1	1:0.33	1:0.5	1:0.75	1:1	1:1.17
Residence time, h	X2	1.3	4	8	12	14.7
Initial moisture content, %	X3	8.64	10	12	14	15.36

$$y = \beta o + \sum_{i=1}^{3} \beta_i X_i + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{ij} X_i X_j + \sum_{i=1}^{3} \beta_{ii} X_1^2$$

where, $\beta_0, \beta_{ii}, \beta_{ij}$, are regression coefficients and Xi and Xj are the coded independent variables of seed bead ratio, residence time and initial moisture content while *Yk* is the dependent variable or the measured response.

Using response surface methodology (RSM), an optimum combination of seed-bead ratio,residence time and initial moisture content was determined. The experimental layout was adopted as per Table 2.

Drying experiments were carried out in air tight containers, mixing seed with beads at room temperature for specified resident times. Seed and beads were mixed in the specific ratio (1:0.33, 1:0.5, 1:0.75, 1:1, 1:1.17) and the residence times were 1.3, 4, 8, 12, 14.7 h as per experimental design. The seed and bead were separated using sieve. Final moisture content of separated seed was determined using standard hot oven method.

Numerical optimization

The optimum level of the selected variables was obtained

Table 2 Experimental layout

Expt. No.	Coded levels		
	X_1	X_2	X_3
1	0	0	0
2	0	0	0
3	0	-1.68	0
4	0	1.68	0
5	1	-1	-1
6	1	1	1
7	0	0	0
8	-1	-1	1
9	1	1	-1
10	-1	1	1
11	-1	1	-1
12	0	0	-1.68
13	0	0	0
14	1	-1	1
15	0	0	0
16	-1.68	0	0
17	0	0	1.68
18	0	0	0
19	-1	-1	-1
20	1.68	0	0

by solving the regression equation using a multi-stage Monte-Carlo optimization (Conley 1984) program and also by analysing the response-surface plots (Khuri and Cornell 1987). Numerical optimization for the process parameters led to the preparation of a drying protocol for obtaining the best results. Desired goals were assigned for all the parameters for obtaining the numerical optimization values for the responses. All the processing parameters were minimized except initial moisture content. Final moisture was minimized while germination percentage and vigour index were maximized. Design Expert 8.0.7.1 software was used for numerical optimization.

RESULTS AND DISCUSSION

The study demonstrated that the tomato and onion seeds could be dried to 2.8% and 3.6%, respectively from 8 – 16% moisture content with beads even at room temperature. Seed-bead ratio, residence time and initial moisture content had found significant effect on drying extent (final moisture content) for both the seeds. It was observed that the seed bead ratio and residence time had a negative correlation with final moisture content (Fig 1). Seed bead ratio expressively affected the drying rate as well as drying extent. The lower final moisture content with increase in seed bead ratio may be attributed to the higher surface area available for moisture adsorption in beads drying.It all described the capability of beads drying to ultra-drying level. The ultra-drying is a proven aid for enhancing longevity of seed (Zheng *et al.* 2001 and Pandita *et al.* 2003).The residence time and initial moisture content had significant effect on an important seed quality trait, i.e. germination percentage ($P < 0.01$) for seeds under the study (Table 3 and 4).However, seed bead ratio was found to be insignificant with respect to germination percentage of both the seeds. The dried tomato and onion seed expressed germination percentage in the range of 71 -78% and 68 – 74%, respectively. Moisture content below 4%, expressed significant reduction in seed quality attributes. It may be due to desiccation of structural water from seed which has also been reported by Ellis and Roberts (1980). The level of germination of both the seeds were found higher than IMCS (Indian Minimum Seed Certification Standards) of respective crop seeds when dried up to more than 4% moisture content. Unlike, hot air drying system, there was no adverse effect of drying on seed quality. Hot air drying induces hydrolysis of starch in the embryonic axis and in turn affects seed germination significantly (Seyedin *et al.* 1984).

The dried tomato and onion seeds demonstrated significantly high vigour. This clearly indicated that there was no any adverse effect on seed quality of bead drying. However, Siddique and Wright (2003) reported that hot air drying induced injury to seed by enzyme inactivation and causing rapid loss of viability. It signifies superiority of beads drying over hot air drying. Positive correlation was demonstrated by residence time with vigour. However, initial moisture content illustrated negative correlations. Residence time was found to be negatively correlated with vigour ($P< 0.05$). It was also strengthened by surface plots (Fig 1).

Table 3 ANOVA and regression coefficients of the second order polynomial model of the various responses for tomato seeds

Predictor	Regression coefficients			
	FMC	GP	VI I	VI II
Intercept	3.68	77.17	11372	1877.58
X_1	-0.15**	0.12	24.88	18.49
X_2	-0.65***	1.10***	298.90***	43.50***
X_3	0.63***	-1.45***	-391.16***	-53.16***
X_1X_2	-0.14	0.25	58.36	24.01
X_1X_3	-0.012	0	-0.21	-12.24
X_2X_3	-0.14	0.75	213.74	21.86
X_1^2	0.008	0.096	32.56	-10.44
X_2^2	0.097	-0.26	-82.71	-8.87
X_3^2	0.18***	0.97***	-297.67**	-35.90**
ANOVA				
R^2	96.59	84.42	84.98	81.22
Model F value	31.49***	6.02***	6.29***	4.81**
CV	5.38	1.43	2.69	2.59
Lack of Fit	NS	NS	NS	NS

Table 4 ANOVA and regression coefficients of the second order polynomial model of the various responses for onion seeds

Predictor	Regression coefficients			
	FMC	GP	VI I	VI II
Intercept	4.60	73.02	8036.58	2185.83
X_1	-0.27***	0.83**	-33.90	103.81
X_2	-0.80***	-1.12***	168.57	-127.97
X_3	0.18**	-0.79**	307.56**	91.63
X_1X_2	0.03	-0.25	81.58	-155.63
X_1X_3	-0.07	0.25	-139.18	13.13
X_2X_3	-0.20	0.75	-127.75	-35.87
X_1^2	0.01	-0.10	66.04	53.75
X_2^2	0.26***	-0.81**	116.70	-5.29
X_3^2	0.37***	-1.16***	235.43**	33.95
ANOVA				
R^2	94.25	87.55	68.44	48.83
Model F value	18.23	7.80	2.40	1.06
CV	5.65	1.36	4.45	12.48
Lack of Fit	NS	NS	NS	

The best fitted second degree polynomial regression model obtained after removing non-significant terms for prediction of germination percentage, vigour and final moisture content using SBR, RT and IMC for tomato and onion seeds (Table 5). High value of R^2 clearly indicated adequacy of the model. Negative coefficient of initial moisture content in germination and vigour models indicated that germination and vigour reduces with increase in values

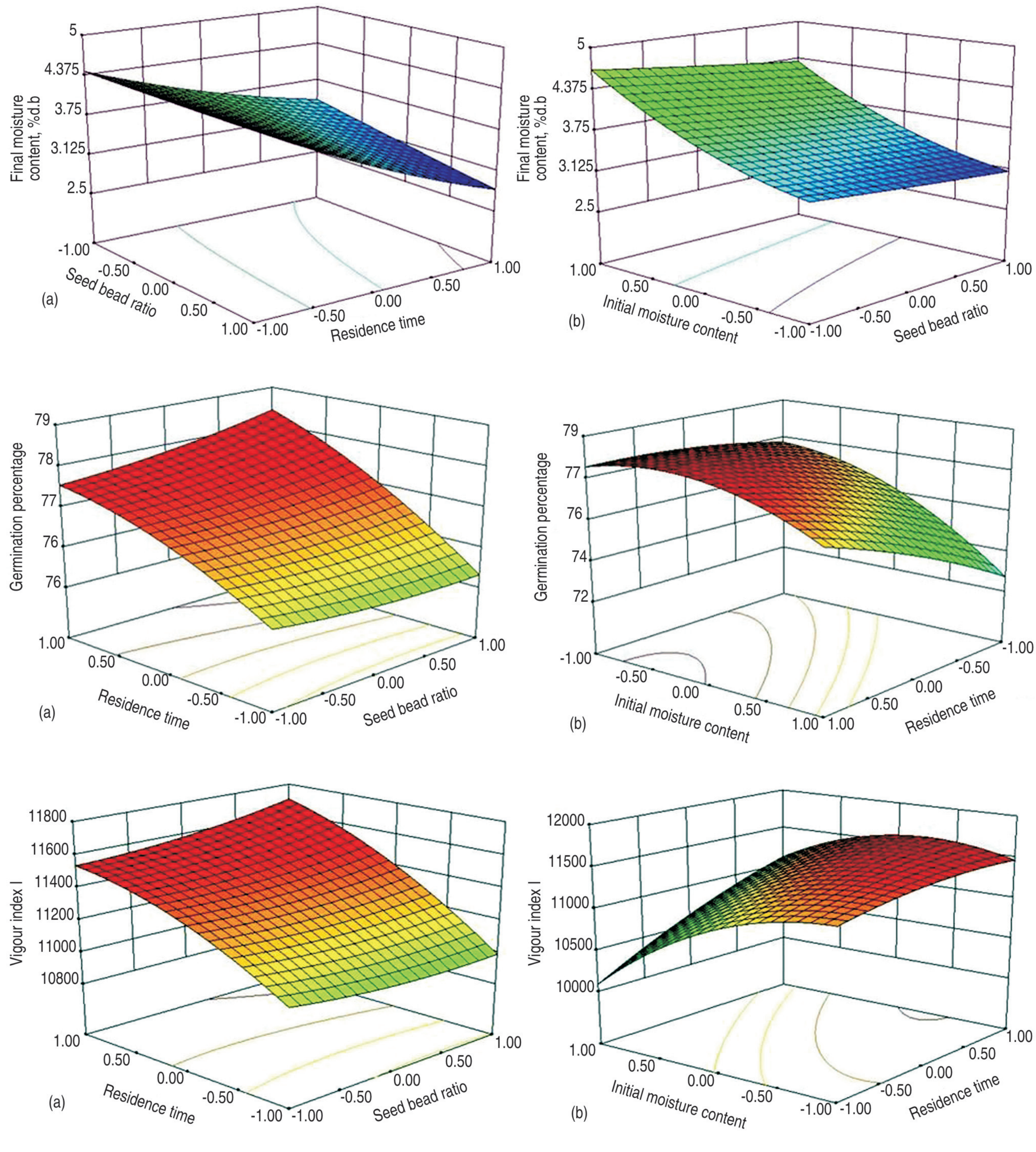

Fig 1 Effect of seed bead ratio, residence time and initial moisture content on germination percentage, vigour indices and final moisture content for tomato seed.

of the initial moisture content. However, presence of negative quadratic term in germination percentage and vigour models of initial moisture content revealed that linearity of change in germination and vigour was limited to limited range of initial moisture content, beyond which there was decrease in germination percentage and vigour more rapidly. However, presence of positive quadratic term of initial moisture content was found in FMC model; which indicated that final moisture content linearity was progressed to limited range after which there was a rapid increase of final moisture content. Linear positive coefficient was observed with residence time for germination and vigour. However, seed-bead ratio was not found significant for affecting seed quality parameters of tomato and onion seeds. It implied that the beads were not affecting the quality of seed during the drying period. Higher rate of drying had been observed with the beads without impairing the seed quality traits, e.g. germination and vigour; unlike to other drying methods.

Table 5 Model equations for germinabilty, vigour and final moisture content for tomato and onion seed

Model equation	R^2	CV
$FMC_t = 3.68 - 0.15\ SBR - 0.65\ RT + 0.63\ IMC + 0.18b\ IMC^2$	96.59	5.38
$FMC_o = 4.59 - 0.27\ SBR - 0.80\ RT + 0.18\ IMC - 0.26\ RT^2 + 0.37\ IMC^2$	94.25	5.65
$GP_t = 77.17 + 1.10\ RT - 1.45\ IMC - 0.96\ IMC^2$	84.42	1.43
$GP_o = 73.02 + 0.83\ SBR + 1.12\ RT - 0.79\ IMC - 0.81\ IMC^2$	87.55	1.36
$VI_t = 1.1372.02 + 298.75\ RT - 391.07\ IMC - 297.19\ IMC^2$	84.98	2.69
$VI_o = 1877.58 + 43.5\ RT - 53.16\ IMC - 35.91\ IMC^2$	81.22	2.59

The overall optimum values for tomato seeds obtained for seed bead ratio, residence time and initial moisture content of tomato seeds were 1:0.5, 10.8 and 11.84%, respectively. The corresponding values for responses, i.e. final moisture content and germination percentage of tomato were 3.94 and 76.99% with high seed vigour, respectively. However, the optimum values for seed bead ratio, residence time and initial moisture content were 1:0.62, 6.52 and 13.62, respectively for onion seeds. The corresponding values of responses for onion seed were found to be 5.55 % and 71.08 with high seed vigour.

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