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Determination of Processing Conditions for Gorgon Nut (*Euryale ferox*)

S. N. Jha;* Suresh Prasad†

* Dairy Engineering Division, National Dairy Research Institute, Karnal, Haryana—132 001, India
† Post Harvest Technology Centre, Indian Institute of Technology, Kharagpur, West Bengal—721 302, India

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Notation

ER	expansion ratio
d_m	diameter of makhana, mm
d_n	diameter of nut, mm
r	correlation coefficient
t	shell thickness, mm
T_f	first roasting temperature, °C
T_s	second roasting temperature, °C
θ_f	first roasting time, min
θ_s	second roasting time, min
θ_p	tempering period, h
Y	recovery of grade 1 makhana, %

Gorgon nuts are processed for their kernels in expanded form and this is known as makhana in India. Operations involved in the traditional method of processing make it laborious, time consuming and costly. This paper reports an investigation into the effect of five combinations of operations on recovery of makhana, viz., (1) roasting and popping; (2) drying, roasting and popping; (3) drying, tempering, roasting and popping; (4) first roasting, tempering, second roasting and popping; and (5) drying, first roasting, tempering, second roasting and popping. The design of the experiments was based on response surface methodology and they were conducted using thin-layer drying and a manual roasting method.

The best combination of operations, based on the recovery of grade 1 makhana, was found to be number 5 above, that is, drying, first roasting, tempering, second roasting and popping. The data was analysed to find the optimum processing conditions, to give 97% grade 1 makhana. These were found to be a combination of first roasting of dried nut (moisture content 33% d.b.) at 335°C for 3·9 min, tempering for 23 h and second roasting at 335°C for 2·8 min. These conditions reduced the processing time to less than one-half as compared with the traditional method.

1. Introduction

The gorgon nut, seed of an aquatic herb, is a monotypic genus of the family Nymphaeaceae and is characterized by its hard seed coat (shell), black colour and round shape, with a diameter ranging from about 4·5 mm to 15 mm (*Fig. 1*). It is grown in the stagnant fresh water pools of the north and north-eastern states of India. Wild populations are also found in China, Japan, USSR, and North America.[1] The nuts are collected from the water and popped to remove the edible starchy kernel. Popping is the process of creating superheated vapour within the conditioned nut by heating the contained moisture and suddenly releasing the pressure to cause a volume expansion of the kernel. The expanded kernel of the nut obtained through this process is called popped kernel and is known as makhana in India. Makhana is utilized in the preparation of curry and puddings. Salted and fried makhana is served as a snack with tea and coffee. It is also used in religious rituals and is a good source of starch for the textile industries.[2]

Presently, gorgon nuts are popped by the traditional method. Operations involved are drying, first roasting, tempering for 48 to 72 h, second roasting and popping. Since, gorgon nut has a hard shell, pressure developed within it is not sufficient to break the shell for expansion of the kernel. An impact force is applied by means of a wooden hammer (mallet) to the hot roasted nut to develop cracks in the shell. As soon as cracks develop, the kernel comes out from the shell in expanded form due to the sudden release of pressure. Makhana is graded for marketing and split-shells are

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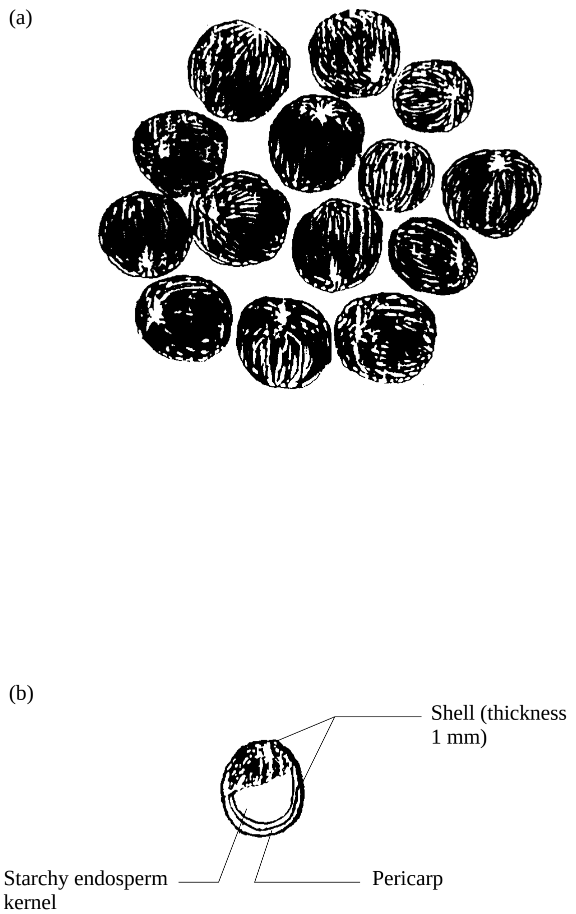

Fig. 1. (a) Whole gorgon nuts; (b) Detail of a gorgon nut

used as a fuel for roasting of the nut. (David and Mishra,[3] Singh,[4] Jha and Prasad[5] and Jha and Kumar[6]). These operations are performed manually and cause injuries to processors' hands, besides giving low output and poor quality (non-uniform and/or little expansion, flattening of the popped kernel). The large number of operations make the processing laborious, time consuming and costly. There is, however, little information in the published literature and almost no research on processing of gorgon nut has been reported so far. It is, therefore, essential to evaluate the effect of each operation and of the variables on expansion and recovery of makhana, which may help in mechanizing the process, reducing the processing time, reducing drudgery of the operations and the processing cost. The object of the present work was to investigate the effect of various combinations of operations involved in the traditional method of processing and to optimize the parameters involved in the selected combination of operations, based on expansion and recovery of makhana.

2. Experimental plan

The raw gorgon nuts of local variety were procured from a merchant of Madhubani, Bihar (India). The moisture content of nut was determined by a vacuum oven method[7] and expressed as a percentage on a dry basis (d.b.). Gorgon nuts were divided into three categories based on their largest dimensions, i.e. small <8 mm; 8–10 mm medium and large >10 mm. The medium size nuts which constitute about 80% of a lot[8] were used in this study.

2.1. *Combinations of operations studied*

The combinations of operations considered were: (1) roasting and popping (RP); (2) drying, roasting and popping (DRP); (3) drying, tempering, roasting and popping (DTRP); (4) first roasting, tempering, second roasting and popping (RTRP); and (5) drying, first roasting, tempering, second roasting and popping (DRTRP) to explore the possibility of maximum recovery of makhana. These combinations were selected with a view to eliminating some of the operations, if possible, or to shorten the processing time.

2.2. *Design of experiments*

An experiment was designed for each combination of operations according to the central composite rotatable design of response surface methodology (RSM).[9] RSM is a collection of mathematical and statistical techniques used in the empirical study of relationships and optimization, where several independent variables influence the response of a dependent variable.

The advantage of this design is that fewer measurements are required to obtain useful and valid information without sacrificing "precision". "Coded values" of the variables are used as defined below and set out in Tables 1 and 2 for RTRP and DRTRP

$$\text{Coded value} = \frac{\text{Natural value} - \text{Base level (level 0)}}{\text{Interval of variation}} \qquad (1)$$

The relationships between the coded and natural values in the RSM design for the experiments are given as follows

$$X_1 = \frac{(T_f - 300)}{50}; \quad X_2 = \frac{(\theta_f - 3)}{1}; \quad X_3 = \frac{(\theta_p - 18)}{6};$$

$$X_4 = \frac{(T_s - 300)}{50}; \quad X_5 = \frac{(\theta_s - 3)}{1}$$

Table 1
Levels, codes and intervals of variation of independent variables in case of RTRP and DRTRP for processing of gorgon nut

Factors	*Codes*	*Levels* −2	−1	0	+1	+2	*Interval of variation*
First roasting temperature, °C	X_1	200	250	300	350	400	50
First roasting time, min	X_2	1	2	3	4	5	1
Tempering period, h	X_3	6	12	18	24	30	6
Second roasting temperature, °C	X_4	200	250	300	350	400	50
Second roasting time, min	X_5	1	2	3	4	5	1

Table 2
Plan of experiments of RTRP and DRTRP for processing of gorgon nut (second order design in the five variables)

Treatment no.	*Coded values of the factors*					*Natural values of the factors*				
	X_1	X_2	X_3	X_4	X_5	X_1	X_2	X_3	X_4	X_5
1	−1	−1	−1	−1	1	250	2	12	250	4
2	1	−1	−1	−1	−1	350	2	12	250	2
3	−1	1	−1	−1	−1	250	4	12	250	2
4	1	1	−1	−1	1	350	4	12	250	4
5	−1	−1	1	−1	−1	250	2	24	250	2
6	1	−1	1	−1	1	350	2	24	250	4
7	−1	1	1	−1	1	250	4	24	250	4
8	1	1	1	−1	−1	350	4	24	250	2
9	−1	−1	−1	1	−1	250	2	12	350	2
10	1	−1	−1	1	1	350	2	12	350	4
11	−1	1	−1	1	1	250	4	12	350	4
12	1	1	−1	1	−1	350	4	12	350	2
13	−1	−1	1	1	1	250	2	24	350	4
14	1	−1	1	1	−1	350	2	24	350	2
15	−1	1	1	1	−1	250	4	24	350	2
16	1	1	1	1	1	350	4	24	350	4
17	−2	0	0	0	0	200	3	18	300	3
18	2	0	0	0	0	400	3	18	300	3
19	0	−2	0	0	0	300	1	18	300	3
20	0	2	0	0	0	300	5	18	300	3
21	0	0	−2	0	0	300	3	6	300	3
22	0	0	2	0	0	300	3	30	300	3
23	0	0	0	−2	0	300	3	18	200	3
24	0	0	0	2	0	300	3	18	400	3
25	0	0	0	0	−2	300	3	18	300	1
26	0	0	0	0	2	300	3	18	300	5
27	0	0	0	0	0	300	3	18	300	3
28	0	0	0	0	0	300	3	18	300	3
29	0	0	0	0	0	300	3	18	300	3
30	0	0	0	0	0	300	3	18	300	3
31	0	0	0	0	0	300	3	18	300	3
32	0	0	0	0	0	300	3	18	300	3

The ranges of variables were selected on the basis of a preliminary study of the traditional method. Variables involved in the drying operation of DRTRP were not included in the design because drying air temperature and time within the ranges of 40 to 60°C and 65 to 99 min respectively, do not appear to affect the recovery and expansion of makhana.[10] The dried sample (moisture content 33·2%) of gorgon nut, instead of raw nuts, was used in DRTRP.

3. Experimental procedure

Raw gorgon nut with an initial moisture content of 60% was dried in a thin layer dryer. The velocity of drying air was fixed at 50 m/min. The dry and wet bulb temperatures of ambient air were recorded by means of mercury thermometers. The temperature of the drying air was maintained by switching heaters on and off.

The roasting operation was carried out in a cast iron open pan by using an electric heater of 1·5 kW or gas burner as a heat source. The pan surface temperature was measured by means of a mercury thermometer of range 0° to 500°C with 1°C graduations. Later, the recorded temperatures were verified by fixing an iron–constantan (J-type) thermocouple to the pan surface. Temperature was measured with an electronic digital temperature indicator. The gorgon nut was put into the pan in a multilayer (50 mm deep) for the first roasting and in a single layer for the second roasting, and agitated continuously. The time of roasting was recorded by means of a digital stop watch. Roasted or dried nuts, depending upon the test combinations, were kept in different containers for different tempering periods at ambient conditions. The tempered and hot roasted nuts were popped by the traditional method to get the expanded kernel (makhana). The expansion ratio of individual makhana, other than those which cracked or burst during processing, was calculated by the following expression

$$ER = \frac{d_m^3}{(d_n - 2t)^3} \quad (2)$$

Makhana having an expansion ratio of more than 20 and no visible crack on its surface were designated as grade 1. makhana with any visible crack, irrespective of expansion ratio, were classified as grade 2. makhana with an expansion ratio less than 20 without any visible crack were categorized as grade 3. The recovery of each grade of makhana was determined as a percentage of makhana obtained from 100 roasted nuts. Nuts which did not produce any makhana were discarded.

Table 3

Effect of processing parameters of RP on recovery and grade of makhana. Initial moisture content of gorgon nut: 60·5% d.b. Layer of nut in pan: single

Treatment no.	Roasting		Recovery of makhana (%)	Grade of makhana		
	Temp. (°C)	Time (min)		1 (%)	2 (%)	3 (%)
1	250	2	0·0	0	0	0
2	350	2	60·0	0	0	100
3	250	4	84·0	0	0	100
4	350	4	100·0	0	10	90
5	229·3	3	10·0	0	0	100
6	370·7	3	80·0	0	0	100
7	300	1·586	0·0	0	0	0
8	300	4·414	100·0	0	13	87
9–13	300	3	82·0*	0	0	100

* Average of five base level observations.

3.1. *Analysis*

The results of the experiments conducted for the various processing methods i.e. RP, DRP, DTRP, RTRP and DRTRP were compared in terms of recovery of grade 1 makhana. A computer program for multiple regression analysis and optimization of data of the best test combinations was made and run on a mainframe computer, Cyber 180/120. There was provision within the program to discard the terms of the regression models having F-values less than 1 which are not significant.[11] The recomputed coefficients of the remaining terms of the model were further subjected to the F-test at 1 and 5% levels of significance. The characteristic roots (lambda) of the coefficients' matrix and the stationary points of the response surface were also generated, and sign of lambda values for maxima/minima or saddle points of stationary values was studied. The points of

Table 4

Effect of processing parameters of DRP on recovery and grade of makhana. Initial moisture content of gorgon nut: 60·1% d.b. Ambient air dry bulb temperature: 31 ± 2°C. Ambient air wet bulb temperature: 25·5 ± 0·5°C. Drying and roasting bed thickness: single layer

Treatment no.	Drying		Roasting		Recovery of makhana (%)	Grade of makhana		
	Temp. (°C)	Time (min)	Temp. (°C)	Time (min)		1 (%)	2 (%)	3 (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	50	45	250	2	0	0	0	100
2	70	45	250	2	10	0	0	100
3	50	75	250	2	8	0	0	100
4	70	75	250	2	60	0	0	100
5	50	45	350	2	5	0	0	100
6	70	45	350	2	70	0	0	100
7	50	75	350	2	60	0	0	100
8	70	75	350	2	74	0	0	100
9	50	45	250	4	91	0	0	100
10	70	45	250	4	93	0	0	100
11	50	75	250	4	96	0	0	100
12	70	75	250	4	98	0	0	100
13	50	45	350	4	100	0	100	0
14	70	45	350	4	100	0	80	20
15	50	75	350	4	100	0	100	0
16	70	75	350	4	100	0	100	0
17	40	60	300	3	80	0	0	100
18	80	60	300	3	91	0	0	100
19	60	30	300	3	83	0	0	100
20	60	90	300	3	90	0	0	100
21	60	60	200	3	0	0	0	100
22	60	60	400	3	100	0	60	40
23	60	60	300	1	0	0	0	100
24	60	60	300	5	88	0	0	100
25–31	60	60	300	3	80*	0	0	100

* Average of seven base level observations.

maxima/minima of stationary values were verified experimentally. The experiments were replicated five times to ascertain the optimum conditions for gorgon nut processing. The mean and standard deviations of the data were reported.

4. Results and discussion

The recovery of makhana was found to be 100% for some treatment combinations and much less than this for others (Tables 3, 4 and 5). This may be owing to intimate contact between the kernel and the shell of the nut at the initial high moisture content which inhibits the shell from breaking completely in the absence of either tempering or secondary roasting in these test combinations. Recovery of grade 1 makhana was found to be nil in the case of RP, DRP and DTRP (Tables 3, 4 and 5), whereas the maximum recovery values were 58% and 93% in RTRP and DRTRP respectively (Table 6). The high temperature treatment and tempering between two roastings in RTRP probably succeeded in breaking the intimate contact between the shell and the kernel, but the second roasting took relatively more time to reduce the moisture to an appropriate level, i.e. about 12%, which probably caused bursting of the kernel and thereby, yielded a greater amount of grade 2 makhana (Table 6). This indicated that the first roasting and tempering followed by the second roasting were the most important operations for processing of gorgon nut. The first roasing at high temperature removes

Table 5

Effect of processing parameters of DTRP on recovery and grade of makhana. Initial moisture content of gorgon nut: 60·1% d.b. Ambient air dry bulb temperature: 32 ± 2°C. Ambient air wet bulb temperature: 25·7 ± 0·5°C. Drying and roasting bed thickness: single layer

Treatment no.	*Drying*		*Tempering*	*Roasting*		*Recovery of Makhana*	*Grade of makhana*		
	Temp. (°C)	*Time (min)*	*(h)*	*Temp. (°C)*	*Time (min)*	*(%)*	*1 (%)*	*2 (%)*	*3 (%)*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	50	45	12	250	4	93	0	0	100
2	70	45	12	250	2	43	0	0	100
3	50	75	12	250	2	9	0	0	100
4	70	75	12	250	4	100	0	60	40
5	50	45	24	250	2	30	0	0	100
6	70	45	24	250	4	95	0	0	100
7	50	75	24	250	4	97	0	0	100
8	70	75	24	250	2	73	0	0	100
9	50	45	12	350	2	28	0	0	100
10	70	45	12	350	4	100	0	78	22
11	50	75	12	350	4	100	0	83	17
12	70	75	12	350	2	85	0	0	100
13	50	45	24	350	4	100	0	90	10
14	70	45	24	350	2	83	0	0	100
15	50	75	24	350	2	83	0	0	100
16	70	75	24	350	4	100	0	100	0
17	40	60	18	300	3	89	0	0	100
18	80	60	18	300	3	99	0	0	100
19	60	30	18	300	3	91	0	0	100
20	60	90	18	300	3	94	0	0	100
21	60	60	6	300	3	60	0	0	100
22	60	60	30	300	3	79	0	0	100
23	60	60	18	200	3	34	0	0	100
24	60	60	18	400	3	100	0	88	12
25	60	60	18	300	1	0	0	0	100
26	60	60	18	300	5	96	0	0	100
27–32	60	60	18	300	3	76*	0	0	100

* Average of six base level observations.

Table 6

Effect of processing parameters of RTRP and DRTRP on recovery and grade of makhana. Initial moisture content of gorgon nut: 60·1% d.b. (for RIRP). Moisture content of dried nut: 33·2% d.b. (for DRTRP). Layer of nut in first roasting: multilayer (50 mm deep). Layer of nut in second roasting: single

Treatment no.*	*RTRP* Recovery of makhana (%)	*RTRP* Grade of makhana 1 (%)	*RTRP* Grade of makhana 2 (%)	*RTRP* Grade of makhana 3 (%)	*DRTRP* Recovery of makhana (%)	*DRTRP* Grade of makhana 1 (%)	*DRTRP* Grade of makhana 2 (%)	*DRTRP* Grade of makhana 3 (%)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
1	100	0	10	90	100	8	64	28
2	80	0	0	100	96	6	0	94
3	88	0	0	100	83	7	0	93
4	100	0	70	30	100	24	76	0
5	100	0	0	100	100	0	0	100
6	100	0	68	32	100	14	86	0
7	100	10	70	20	100	33	50	17
8	100	0	0	100	100	62	0	38
9	78	0	0	100	100	43	0	57
10	90	12	78	10	100	26	68	6
11	93	14	86	0	100	13	87	0
12	90	37	0	63	100	88	8	4
13	100	58	42	0	100	21	66	13
14	100	0	0	100	100	65	0	35
15	100	0	0	100	100	82	0	18
16	100	12	88	0	100	25	69	6
17	92	0	0	100	100	11	0	89
18	94	40	0	60	100	93	0	7
19	90	0	0	100	100	0	0	100
20	98	0	0	100	100	81	16	3
21	60	0	0	100	51	39	0	12
22	100	0	0	100	100	89	0	11
23	90	0	0	100	100	0	0	100
24	96	56	0	44	100	64	10	26
25	86	0	0	100	100	0	0	100
26	100	0	89	11	100	27	73	0
27–32	98†	0	0	100	100	88†	0	12†

* Treatments are as indicated in Table 2.
† Average of six base level observations.

moisture faster from the shell than from the kernel and gelatinizes the starch content of the kernel. During tempering, the roasted nuts are cooled slowly to room temperature which causes shrinkage in the kernel and the shell at different rates. The differential rate of shrinkage breaks the close contact between the two and facilitates the loosening of the kernel within the shell.[12] The inclusion of a drying operation to dry the nuts to about 33% moisture content before the first roasting further enhances the recovery of grade 1 makhana (Table 6) which revealed that the DRTRP combination of operations may be the most appropriate for recovery of the highest percentage of grade 1 makhana.

Results of DRTRP revealed that the recovery of makhana in most cases was 100%, whereas the recovery of grade 1 makhana varied significantly (Table 6). The regression model for the data of DRTRP in Table 6, after discarding the terms of F-value less than 1, for recovery (Y%) of grade 1 makhana was found to be as follows ($r = 0{\cdot}9387$)

$$Y = -1556 + 2{\cdot}49T_f + 98{\cdot}49\theta_f + 6{\cdot}57\theta_p + 4{\cdot}2T_s + 222{\cdot}32\theta_s - 0{\cdot}0033T_f^2 - 0{\cdot}1T_f\theta_s - 11{\cdot}15\theta_f^2 - 6{\cdot}2\theta_f\theta_s - 0{\cdot}15\theta_p^2 - 0{\cdot}0053T_s^2 - 0{\cdot}25T_s\theta_s - 17{\cdot}9\theta_s^2 \quad (3)$$

Table 7
Analysis of variance for recovery of grade 1 makhana by DRTRP combination of operations

Sources of variation	*Reduction in sum of squares*	*Degrees of freedom*	*Mean sum of squares*	*F-value computed*
T_f	2809·654	1	2809·654	10·992**
θ_f	5296·591	1	5296·591	20·722**
θ_p	1225·094	1	1225·094	4·793*
T_s	8018·102	1	8018·102	31·37**
θ_s	7806·740	1	7806·740	30·543**
T_f^2	2007·515	1	2007·515	7·854*
$T_f \times \theta_s$	351·562	1	351·562	1·375^{ns}
θ_f^2	3645·307	1	3645·307	14·262**
$\theta_f \times \theta_s$	612·562	1	612·562	2·396^{ns}
θ_p^2	815·515	1	815·515	3·191^{ns}
T_s^2	5167·515	1	5167·515	20·217**
$T_s \times \theta_s$	2425·563	1	2425·563	9·490**
θ_s^2	9396·307	1	9396·307	36·762**
Error	4600·756	18	255·597	

	Stationary points	*Lambda values*
T_f	339·3	−0·003
θ_f	3·9	−0·004
θ_p	23·0	−0·134
T_s	332·8	−9·956
θ_s	2·3	−19·103

F value at 1% (1, 18) = 8·28, at 5% (1, 18) = 4·41.
* Significant at 5% level.
** Significant at 1% level.
ns, Not significant.

The adequacy of the model [Eqn (3)] was tested by constructing analysis of variance (ANOVA) in Table 7.

The coefficients of each term of the model were subjected to the *F*-test to determine the significance at 1% and 5% probability levels with 1 and 18 degrees of freedom.[11] Square of tempering period (θ_p) and interactions of the second roasting time (θ_s) with the first roasting temperature (T_f) and time (θ_f) were statistically not significant at the 5% level, whereas tempering period (θ_p) and square of the first roasting temperature (T_f) were significant at the same level. Comparison of coefficients of terms of the same units of Eqn (3) reveals that the second roasting temperature and time are the most significant factors, although other factors are also significant.

Optimum levels of process variables were determined based on the signs of lambda values (characteristic roots of coefficients' matrix. The positive and negative sign of all the lambda values indicate the minima and maxima respectively at the corresponding stationary points of independent variables.[11] The negative sign of the lambda values in Table 7, thus, indicates that the recovery of grade 1 makhana may be maximum at the stationary points. Experimental results at stationary points (Table 8) confirm, by comparing with the results of Table 6, that the recovery of grade 1 makhana is maximum (98%) at stationary points which were found to be the first roasting at about 339°C for 3·9 min, tempering of nut for 23 h and second roasting at 333°C for 2·3 min (Table 8).

In general, the first and second roasting temperatures are kept the same for the convenience of the processors. It is, therefore, desirable to have only one temperature for both roastings; if this is done, other parameters of optimum conditions, viz. roasting times and tempering period, will change. To determine this change, data were generated at various second roasing temperatures and times, keeping first roasting temperature, time and tempering period constant at 335°C (near to mean of optimum temperatures for both roastings), 3·9 min and 23 h respectively, by using Eqn (3) to plot a response surface for recovery of grade 1 makhana by means of standard computer software (*Fig. 2*). The figure shows that increasing the second

Table 8

Recovery of grade 1 makhana at stationary points and recommended optimum conditions. Initial moisture content of gorgon nut: 33·2% d.b. Layer of nut in first roasting: multi-layer (50 mm deep). Layer of nut in second roasting: single

First roasting		*Tempe-ring*	*Second roasting*		*Recovery of makhana*	*Means of grade of makhana*		
Temp. (°C)	*Time (min)*	*(h)*	*Temp. (°C)*	*Time (min)*	*(%)*	*1 (%)*	*2 (%)*	*3 (%)*
339	3·9	23	333	2·3	100	98 (1·6)	0·0 (0)	2·0 (1·6)*
335	3·9	23	335	2·85	100	97 (1·6)	1·2 (1·1)	1·8 (1·1)

* Numbers in parentheses indicate standard deviations.

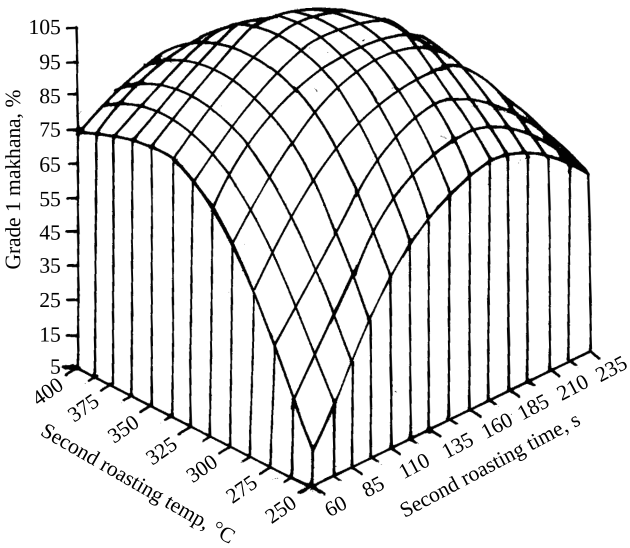

Fig. 2. Response surface of grade 1 makhana recovery by DRTRP combination of operations at $T_f = 335°C$; $\theta_f = 3{\cdot}9$ min and $\theta_p = 23$ h

roasting time increased the recovery of grade 1 makhana at all temperatures up to 171 s roasting time beyond which there was a levelling off followed by a decline. Maximum recovery of grade 1 makhana occurs at a second roasting temperature of 335°C for 171 s and this was verified experimentally. Recovery of grade 1 makhana was found to be 97%, only 1% less than the maximum recorded in Table 8. Thus, the optimum conditions may be taken as: first roasting of dried nut at 335°C for 3·9 min; tempering period of 23 h; and second roasting temperature of 335°C for 171 s (2·85 min). These optimum conditions indicate that a tempering period of 23 h is required for gorgon nut processing as compared with 48 to 72 h in the traditional method.[5] Thus, the processing time may be reduced to less than one-half of that of the traditional method.

5. Conclusions

1. The best combination of operations for processing of gorgon nut to get the maximum recovery of grade 1 makhana was found to be drying, first roasting, tempering, second roasting and popping.
2. The optimum conditions for gorgon nut processing, which give up to 97% grade 1 makhana, were found to be first roasing of dried nut (moisture content 33·2%) at 335°C for 3·9 min, tempering for 23 h and second roasting at 335°C for 2·85 min, just before applying the impact force to the hot roasted nut for popping.
3. The tempering period between the two roasting operations can be reduced from the 48–72 h of the traditional method to 23 h, thus cutting overall processing time by more than one-half.

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