Moisture dependent physical properties of lathyrus

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Abstract The moisture dependent physical properties of different lathyrus varieties namely NLK-40, Pratik and Ratan were studied at moisture content of 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.), respectively. The grain size, thousand grain weight, angle of repose, grain volume and surface area were found increased linearly. The grain size was found increased from 4.43 to 4.70, 4.96 to 5.32 and 5.08 to 5.49 mm. Thousand grain weight was found increased from 64.6 to 103.5, 69.1 to 105.3 and 85.3 to 125.6 g. The angle repose was increased from 28.3 to 35.4, 29.5 to 35.8 and 26.9 to 33.5°. The grain volume was increased from 9.13 to 10.38, 11.73 to 13.24 and 12.22 to 14.15 mm³ whereas, surface area increased from 54.78 to 62.29, 70.38 to 79.45 and 73.31 to 84.88 mm², respectively with the corresponding increase in moisture content, for NLK-40, Pratik and Ratan. The sphericity and porosity increased initially and then found decreased with increase in further moisture content. The bulk density values decreased linearly from 827.5 to 697.2, 851.3 to 726.3 and 856.0 to 727.4 kg/m³. The true density values were found decreased from 1288.3 to 1074.3, 1324.0 to 1118.4 and 1277.7 to 1102.5 kg/m³, respectively for these varieties with the corresponding increase in moisture content.

Keywords Physical property · Lathyrus · True density · Bulk density · Sphericity · Grain volume · Surface area

Introduction

Physical properties of grains and their dependence on moisture content are of paramount importance in designing equipment for handling, storing and processing. The lathyrus (*Lathyrus sativus* L.) is food, feed and fodder legume (pulse) crop. In India lathyrus is also known as *khesari*, *lakhori* and *lakhodi*. In India the lathyrus grain is used as complimentary or sole source of calories and protein, mostly by poor and landless labours. The grain can be boiled whole but most often they are processed through a pulse (dal) mill to obtain splits. Dal is the most common item sold in retail markets. The flour, made by grinding either whole grain or splits is also sold in the market as *besan*. In many parts of the country *roti* (unleavened bread) made out of *Khesari* is a staple food for the poor's and landless labours during lean periods. It is also reported that lathyrus leaves are used as green vegetable (Castell et al. 1994). It is grown on an area of about 1.5 million hectares with the annual production of 0.8 million tonnes. Nearly two-third of national acreage under lathyrus is in south-eastern Madhya Pradesh, and in the *Vidarbha* region of Maharashtra. India ranks first in area (1500 thousand ha), production (800 thousand tonne) and productivity (533 kg/ha) (Clayton and Campbell 1997). The major lathyrus growing states in India are Madhya Pradesh, Maharashtra, Bihar, West Bengal and Eastern Uttar Pradesh. Rahman et al. (1974) and Rotter et al. (1991) gave the composition for lathyrus as; energy 362.3 cal, protein 31.6%, fat 2.7%, nitrogen-free extract 51.8%, crude fibre 1.1% and ash 2.2% (Tables 1, 2, 3, 4 and 5).

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Table 1 Physical property of different varieties of lathyrus

NLK-40		Pratik		Ratan	
M.C., % d. b.	Mean value	M.C., % d. b.	Mean value	M.C., % d.b.	Mean value
Grain size, mm					
7.33	4.43 (± 0.05)	6.75	4.96 (± 0.02)	7.90	5.08 (± 0.06)
13.10	4.47 (± 0.01)	12.50	5.03 (± 0.03)	13.60	5.22 (± 0.05)
18.80	4.57 (± 0.01)	18.30	5.18 (± 0.02)	19.40	5.33 (± 0.03)
24.52	4.62 (± 0.02)	24.10	5.25 (± 0.01)	25.10	5.41 (± 0.03)
30.29	4.70 (± 0.02)	29.95	5.32 (± 0.01)	30.90	5.49 (± 0.01)
Bulk density, kg/m ³					
7.33	827.5 (± 0.60)	6.75	851.3 (± 0.54)	7.90	856.0 (± 0.72)
13.10	781.4 (± 0.34)	12.50	802.7 (± 0.29)	13.60	807.6 (± 0.81)
18.80	748.3 (± 0.25)	18.30	777.5 (± 0.19)	19.40	775.6 (± 0.65)
24.52	722.5 (± 0.48)	24.10	749.2 (± 0.08)	25.10	745.5 (± 0.44)
30.29	697.2 (± 0.24)	29.95	726.3 (± 0.22)	30.90	727.4 (± 0.04)
True density, kg/m ³					
7.33	1288.3 (± 0.07)	6.75	1324.0 (± 5.23)	7.90	1277.7 (± 0.53)
13.10	1237.7 (± 28.71)	12.50	1286.4 (± 0.12)	13.60	1267.2 (± 0.22)
18.80	1157.6 (± 46.16)	18.30	1229.5 (± 0.09)	19.40	1202.6 (± 0.24)
24.52	1128.5 (± 0.21)	24.10	1169.2 (± 0.14)	25.10	1142.8 (± 0.43)
30.29	1074.3 (± 0.20)	29.95	1118.4 (± 0.09)	30.90	1102.5 (± 0.32)
Porosity, %					
7.33	35.7 (± 0.05)	6.75	35.4 (± 0.29)	7.90	34.6 (± 1.09)
13.10	37.7 (± 0.04)	12.50	37.6 (± 0.02)	13.60	36.2 (± 0.06)
18.80	36.8 (± 0.02)	18.30	36.7 (± 0.02)	19.40	35.5 (± 0.06)
24.52	35.9 (± 0.05)	24.10	35.9 (± 0.02)	25.10	34.7 (± 0.03)
30.29	35.1 (± 0.02)	29.95	35.0 (± 0.02)	30.90	34.0 (± 0.02)
Thousand grain weight, g					
7.33	64.6 (± 0.39)	6.75	69.1 (± 0.31)	7.90	85.3 (± 0.15)
13.10	74.6 (± 0.10)	12.50	78.3 (± 0.12)	13.60	95.3 (± 0.17)
18.80	84.7 (± 0.33)	18.30	87.2 (± 0.13)	19.40	105.3 (± 0.05)
24.52	93.6 (± 0.21)	24.10	96.2 (± 0.09)	25.10	115.4 (± 0.10)
30.29	103.5 (± 0.32)	29.95	105.3 (± 0.34)	30.90	125.6 (± 0.25)
Sphericity, %					
7.33	86.79 (± 1.10)	6.75	88.17 (± 0.21)	7.90	87.49 (± 0.59)
13.10	87.58 (± 0.03)	12.50	87.63 (± 0.45)	13.60	88.67 (± 0.36)
18.80	86.55 (± 0.56)	18.30	87.00 (± 0.46)	19.40	87.92 (± 0.19)
24.52	85.85 (± 0.46)	24.10	86.25 (± 0.39)	25.10	86.77 (± 0.05)
30.29	84.96 (± 0.71)	29.95	85.28 (± 0.19)	30.90	85.85 (± 0.22)
Grain volume, mm ³					
7.33	9.13 (± 0.04)	6.75	11.73 (± 0.01)	7.90	12.22 (± 0.04)
13.10	9.47 (± 0.02)	12.50	12.02 (± 0.05)	13.60	13.00 (± 0.08)
18.80	9.85 (± 0.06)	18.30	12.68 (± 0.02)	19.40	13.51 (± 0.03)
24.52	10.01 (± 0.02)	24.10	12.94 (± 0.02)	25.10	13.81 (± 0.02)
30.29	10.38 (± 0.03)	29.95	13.24 (± 0.03)	30.90	14.15 (± 0.09)
Angle of repose, °					
7.33	28.39 (± 0.58)	6.75	29.54 (± 0.29)	7.90	26.91 (± 0.06)
13.10	30.15 (± 0.30)	12.50	31.09 (± 0.43)	13.60	28.71 (± 0.12)
18.80	32.20 (± 0.55)	18.30	32.26 (± 0.07)	19.40	30.37 (± 0.07)
24.52	33.70 (± 0.21)	24.10	34.53 (± 0.05)	25.10	32.09 (± 0.05)

Table 1 (continued)

NLK-40		Pratik		Ratan	
M.C., % d. b.	Mean value	M.C., % d. b.	Mean value	M.C., % d.b.	Mean value
30.29	35.41 (± 0.02)	29.95	35.84 (± 0.08)	30.90	33.51 (± 0.02)
Surface area, mm ²					
7.33	54.78 (± 0.05)	6.75	70.38 (± 0.14)	7.90	73.31 (± 0.78)
13.10	56.83 (± 0.01)	12.50	72.15 (± 0.05)	13.60	78.01 (± 0.71)
18.80	59.11 (± 0.01)	18.30	76.05 (± 0.06)	19.40	81.01 (± 0.55)
24.52	60.08 (± 0.02)	24.10	77.67 (± 0.08)	25.10	82.88 (± 0.44)
30.29	62.29 (± 0.02)	29.95	79.45 (± 0.02)	30.90	84.88 (± 0.09)

Values in parentheses are standard deviations

Mean values of five replications

In the design of machine, structures certain physical properties of the materials are of paramount importance (Mohsenin 1986). To design a machine for handling, cleaning, conveying, storing and milling, the physical properties of lathyrus at different moisture contents must be known

(Tabatabaeefar 2003). The knowledge of properties can also be used to calculate surface area and volume which are important during modeling of grain drying, aeration, heating and cooling systems (Konak et al. 2002). The data on angle of repose is necessary to design hoppers. Data on densities have

Table 2 Analysis of variance (ANOVA) showing the effect of moisture content on physical properties of lathyrus

Variety	Physical property	DF	SS	MS	F CAL	CD	SD
NLK-40	Grain size	4	0.16	0.04	52.17 ^a	0.04	0.115
	Sphericity	4	85.85	21.46	2.02 ^a	0.83	0.990
	Bulk density	4	31186.10	7796.52	45797.25 ^a	0.54	50.970
	True density	4	88064.23	22016.06	33.53 ^a	34.11	85.666
	Porosity	4	12.22	3.06	1936.30 ^a	0.05	1.009
	1000-grain wt	4	2808.93	702.23	9867.88 ^a	0.35	15.299
	Angle of Repose	4	92.99	23.25	256.55 ^a	0.40	2.783
	Volume	4	2.79	0.70	350.75 ^a	0.06	0.483
	Surface area	4	101.37	25.34	39291.02 ^a	0.03	2.906
Ratan	Grain size	4	0.31	0.08	42.08 ^a	0.06	0.161
	Sphericity	4	14.00	3.50	35.44 ^a	0.42	1.080
	Bulk density	4	31436.41	7859.10	21368.06 ^a	0.81	51.183
	True density	4	69939.56	17484.89	30.67 ^a	31.79	76.340
	Porosity	4	9.00	2.25	9.50 ^a	0.64	0.865
	1000-grain wt	4	3042.19	760.55	27336.55 ^a	0.22	15.922
	Angle of Repose	4	82.60	20.65	3737.73 ^a	0.10	2.623
	Volume	4	6.83	1.71	1232.43 ^a	0.05	0.754
	Surface area	4	245.90	61.47	31851.84 ^a	0.06	4.526
Pratik	Grain size	4	5.25	1.31	1.97 ^a	0.02	0.148
	Sphericity	4	86.25	21.56	2.02 ^a	0.48	1.139
	Bulk density	4	749.27	187.32	2.06 ^a	0.42	48.545
	True density	4	1169.28	292.32	2.09 ^a	3.17	83.746
	Porosity	4	35.92	8.98	2.05 ^a	0.18	1.017
	1000-grain wt	4	96.23	24.06	1.83 ^a	0.32	14.283
	Angle of Repose	4	34.53	8.63	1.93 ^a	0.34	2.545
	Volume	4	12.94	3.24	1.96 ^a	0.04	0.631
	Surface area	4	77.67	19.42	1.96 ^a	0.06	3.788

^a Significant at 5% level of significance

Table 3 Actual, predicted and RMSE values of lathyrus cv. NLK-40

Physical property	Moisture content % (d. b.)	Actual	Predicted	RMSE
Grain size	7.33	4.43	4.41	0.02
	13.10	4.47	4.48	0.01
	18.80	4.57	4.55	0.02
	24.52	4.62	4.62	0.00
	30.29	4.72	4.68	0.03
Sphericity	7.33	86.79	87.01	0.22
	13.10	87.58	87.18	0.40
	18.80	86.55	86.97	0.41
	24.52	85.85	86.35	0.51
	30.29	84.96	85.34	0.38
Bulk density	7.33	827.57	819.36	8.22
	13.10	781.46	787.21	5.75
	18.80	748.37	755.45	7.08
	24.52	722.58	723.57	0.99
	30.29	697.25	691.42	5.83
True density	7.33	1288.32	1284.33	3.99
	13.10	1237.79	1230.27	7.53
	18.80	1157.64	1176.86	19.23
	24.52	1128.50	1123.27	5.22
	30.29	1074.34	1069.21	5.12
Porosity	7.33	35.76	36.08	0.32
	13.10	37.71	36.98	0.72
	18.80	36.81	37.09	0.27
	24.52	35.97	36.41	0.44
	30.29	35.10	34.93	0.17
Thousand grain weight	7.33	64.64	64.85	0.21
	13.10	74.62	74.58	0.04
	18.80	84.71	84.20	0.52
	24.52	93.62	93.85	0.22
	30.29	103.51	103.58	0.07
Angle of repose	7.33	28.39	28.44	0.05
	13.10	30.15	30.21	0.06
	18.80	32.20	31.95	0.25
	24.52	33.70	33.70	0.01
	30.29	35.41	35.47	0.06
Grain volume	7.33	9.13	9.16	0.03
	13.10	9.47	9.47	0.00
	18.80	9.85	9.77	0.08
	24.52	10.01	10.07	0.06
	30.29	10.38	10.38	0.00
Surface area	7.33	54.78	54.96	0.18
	13.10	56.83	56.80	0.03
	18.80	59.11	58.61	0.50
	24.52	60.08	60.44	0.36
	30.29	62.29	62.28	0.01

Mean values of five replications

been used in research for determining the dielectric properties of grains. It is revealed from the literature that the data on moisture dependent physical properties of lathyrus have not

been reported so far. Therefore, present study was planned with objective to determine different moisture dependent physical properties of lathyrus.

Table 4 Actual, predicted and RMSE values of lathyrus cv. Pratik

Physical property	Moisture content % (d.b.)	Actual	Predicted	RMSE
Grain size	6.75	4.96	4.96	0.00
	12.50	5.03	5.05	0.02
	18.30	5.18	5.14	0.03
	24.10	5.25	5.24	0.01
	29.95	5.32	5.33	0.01
Sphericity	6.75	88.17	88.15	0.02
	12.50	87.63	87.66	0.03
	18.30	87.00	87.02	0.02
	24.10	86.25	86.25	0.00
	29.95	85.28	85.34	0.06
Bulk density	6.75	851.32	841.90	9.43
	12.50	802.70	811.83	9.13
	18.30	777.54	781.49	3.95
	24.10	749.27	751.16	1.89
	29.95	726.30	720.56	5.74
True density	6.75	1324.05	1330.51	6.46
	12.50	1286.43	1278.14	8.29
	18.30	1229.55	1225.31	4.24
	24.10	1169.28	1172.47	3.20
	29.95	1118.49	1119.19	0.70
Porosity	6.75	35.49	35.85	0.36
	12.50	37.60	36.92	0.69
	18.30	36.76	37.18	0.42
	24.10	35.92	36.65	0.72
	29.95	35.07	35.29	0.22
Thousand grain weight	6.75	69.15	69.23	0.08
	12.50	78.31	78.18	0.13
	18.30	87.25	87.21	0.04
	24.10	96.23	96.24	0.01
	29.95	105.36	105.35	0.01
Angle of repose	6.75	29.54	29.45	0.09
	12.50	31.09	31.04	0.05
	18.30	32.26	32.64	0.38
	24.10	34.53	34.24	0.29
	29.95	35.84	35.86	0.02
Grain volume	6.75	11.73	11.74	0.01
	12.50	12.02	12.13	0.11
	18.30	12.68	12.52	0.16
	24.10	12.94	12.91	0.03
	29.95	13.24	13.31	0.07
Surface area	6.75	70.38	70.42	0.04
	12.50	72.15	72.77	0.62
	18.30	76.05	75.13	0.92
	24.10	77.67	77.50	0.17
	29.95	79.45	79.88	0.43

Mean values of five replications

Material and methods

The lathyrus samples (cv. Ratan, Pratik and NLK-40) were procured from All India Co-ordinated Research

Project on Lathyrus, Nagpur. These varieties are grown in India. The farmer's livelihood is mostly depending upon the revenue received from cultivation of these varieties of lathyrus. Moisture content of grain samples

Table 5 Actual, predicted and RMSE values of lathyrus cv. Ratan

Physical property	Moisture content % (d.b.)	Actual	Predicted	RMSE
Grain size	7.90	5.08	6.31	1.23
	13.60	5.22	7.28	2.06
	19.40	5.33	8.26	2.93
	25.10	5.41	9.23	3.82
	30.90	5.49	10.22	4.73
Sphericity	7.90	87.49	87.77	0.28
	13.60	88.67	88.34	0.33
	19.40	87.92	88.33	0.41
	25.10	86.77	87.72	0.95
	30.90	85.85	86.50	0.65
Bulk density	7.90	856.04	846.16	9.87
	13.60	807.62	814.53	6.91
	19.40	775.60	782.35	6.75
	25.10	745.56	750.72	5.16
	30.90	727.48	718.54	8.94
True density	7.90	1277.73	1292.77	15.04
	13.60	1267.21	1245.70	21.50
	19.40	1202.60	1197.81	4.78
	25.10	1142.88	1150.75	7.87
	30.90	1102.55	1102.86	0.31
Porosity	7.90	34.64	34.92	0.28
	13.60	36.27	35.67	0.60
	19.40	35.51	35.76	0.25
	25.10	34.76	35.19	0.43
	30.90	34.02	33.95	0.07
Thousand grain weight	7.90	85.31	85.30	0.00
	13.60	95.38	95.28	0.09
	19.40	105.32	105.44	0.12
	25.10	115.46	115.42	0.04
	30.90	125.62	125.58	0.04
Angle of repose	7.90	26.91	27.01	0.10
	13.60	28.71	28.65	0.07
	19.40	30.37	30.32	0.06
	25.10	32.09	31.96	0.13
	30.90	33.51	33.63	0.12
Grain volume	7.90	12.22	12.41	0.19
	13.60	13.00	12.87	0.13
	19.40	13.51	13.34	0.17
	25.10	13.81	13.80	0.01
	30.90	14.15	14.27	0.12
Surface area	7.90	73.31	74.44	1.13
	13.60	78.01	77.22	0.79
	19.40	81.07	80.04	1.03
	25.10	82.88	82.82	0.06
	30.90	84.88	85.64	0.76
Mean values of five replications				

of known weight (about 25 g) was determined following a standard oven drying method at an air temperature of 103 ± 2 °C for 72 h and subsequently cooling in

desiccators for one hour before taking the final weight. Average of five replications was noted and reported as moisture content of the samples. The initial moisture

content of lathyrus sample (cv. Ratan, Pratik and NLK-40) when brought to the laboratory was found to be 7.33, 6.75 and 7.90% (d. b.), respectively.

Physical properties for raw lathyrus were investigated in the simulated moisture range of 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.) respectively, since harvesting, threshing, transportation, drying, milling and storage operations of lathyrus are performed in this range. In order to attain the desired moisture levels for the study, samples were conditioned by adding a calculated amount of distilled water followed by mixing and sealing in plastic bags. The conditioned samples were kept in refrigerator set at 5 ± 1 °C for 10 days for the moisture to distribute uniformly throughout the grains (Konak et al. 2002; Carman 1996; Aydin 2002). Accordingly, moisture levels of 7.33, 13.10, 18.80, 24.52, 30.29; 6.75, 12.50, 18.30, 24.10, 29.95 and 7.90, 13.60, 19.40, 25.10, 30.90% (d.b.) were obtained, respectively, for NLK-40, Pratik and Ratan. The required amount of sample was withdrawn from the refrigerator and reconditioned at room temperature (≈ 28.5 °C) before conducting each test (Carman 1996; Nimkar et al. 2005).

Determination of physical properties

The physical properties, namely grain size, sphericity, bulk density, true density, porosity, thousand grain weight, angle of repose, grain volume and surface area of lathyrus were studied at five different levels of moisture content ranged from 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.) respectively, in order to relate the property to moisture content. The average of five replications was reported for each of the property.

Geometric mean (grain size) is the cube root of product of three semi-axes of grain. Three major principle axes of grain were measured with the help of vernier caliper (Mitutoyo Japan) having least count of 0.02 mm. The grain size (D_m) of the grain was calculated by using the following relationship.

$$D_m = (LBT)^{1/3} \quad (1)$$

where,

D_m grain size, mm
 L length, mm
 B width, mm and
 T thickness, mm

The average observation of 100 randomly selected lathyrus grain was calculated and standard deviation was also determined.

The bulk density of the grain is the ratio of its mass to bulk volume. To measure the bulk density of the grain, the method given in IS: 4333 (Part III)–1967 was used which involves filling up standard kettle of 500 mL with grain from a height of 150 mm and then weighing the contents. Bulk density values of the samples at different moisture content were determined using this technique.

The ratio of mass of sample to the true volume is termed as true density of the sample. True densities were determined with toluene displacement method. Grain sample about 10 g was submerged in toluene in measuring cylinder having an accuracy of 0.1 mL. The increase in liquid volume due to sample was noted as true volume of the sample, which was then used to determine the true density of sample.

The porosity is the percentage of volume of voids in the test sample at given moisture content. It was calculated as the ratio of the difference in true density and bulk density to the true density value and expressed in percentage with the following equation.

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (2)$$

where

ε porosity, %
 ρ_t bulk density, kg/m³ and
 ρ_b true density, kg/m³

For determination of thousand grain weight one thousand randomly selected sound grains of the test sample at various moisture levels were collected and weighed on electronic top pan balance (Contech India) having a least count of 0.01 g. This magnitude was termed as the thousand grain weight specific to the grain. The procedure as described in IS: 4333 (Part IV) -1968 was adopted.

Sphericity was calculated by using the equation given by Mohsenin (1986) as follows.

$$\emptyset = \frac{(LBT)^{1/3}}{L} \quad (3)$$

where,

$\emptyset$ sphericity, %
 L length, mm
 B width, mm and
 T thickness, mm

The angle of repose is the angle between the base and slope of cone formed on a free vertical fall of the granular material. It was determined by angle of repose

apparatus as suggested in IS: 6663 (1972). The grain volume and grain surface area was calculated using the equations suggested by Jain and Bal (1997).

$$V = 0.25 \left[\frac{\pi}{6} L(W + L)^2 \right] \quad (4)$$

$$S = \frac{\pi BL^2}{(2L - B)} \quad (5)$$

where,

$$B = \sqrt{WT}$$

The temperature of environment was recorded at five times in a day and the average was recorded as $28.5 \pm 0.5^\circ\text{C}$.

Analysis of variance (ANOVA) was carried out to test the significance of the effect of moisture content on physical properties using SPSS version 10 (SPSS 1999) whereas, regression analysis was employed to describe the relationship between moisture content and respective physical properties.

Results and discussion

Grain size The grain size increased linearly with increase in moisture content as shown in Fig. 1 (a). The grain sizes of NLK-40, Pratik and Ratan were found increased from 4.43 to 4.70, 4.96 to 5.32 and 5.08 to 5.49 mm for corresponding increase in moisture contents of 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.), respectively. The percent increase in grain sizes of these lathyrus grains were 6.54, 7.25 and 8.07%, respectively. This variation in grain sizes with moisture content was significant at 5% level of significance.

The results showing increase in grain size with increase in moisture content were in agreement with the earlier findings for green gram (Nimkar and Chattopadhyay 2001), lentil seed (Amin et al. 2004), fenugreek seeds (Altuntas et al. 2005), kidney bean (Isik and Unal 2007), feba bean (Altuntas and Yildiz 2007), lathyrus (Zewdu and Solomon 2008) and for soybean (Kibar and Ozturk 2008). The variation in grain sizes with moisture content of the grain could be represented by following equations.

$$\text{NLK-40 } D_m = 4.321 + 0.012M \quad (R^2 = 0.983) \quad (6)$$

$$\text{Pratik } D_m = 4.852 + 0.016M \quad (R^2 = 0.982) \quad (7)$$

$$\text{Ratan } D_m = 4.963 + 0.17M \quad (R^2 = 0.981) \quad (8)$$

where,

D_m grain size, mm and

M moisture content, % (d.b.)

Sphericity The results obtained are shown graphically in Fig. 1(b), which indicated that the sphericity of lathyrus grains at different moisture content increased initially and further decreased with increase in moisture content. For NLK-40 the values increased initially from 86.79 to 87.58% with increase in moisture content from 7.33 to 13.10% (d.b.) and then reduced to 84.96% with further increase in moisture content upto 30.29% (d.b.). For Pratik it was increased initially from 87.63 to 88.17% with increase in moisture content from 6.75 to 12.50% (d.b.) and then reduced to 85.28% with further increase in moisture content upto 29.95% (d.b.). For Ratan from 87.49 to 88.67% with increase in moisture content from 7.90 to 13.60% (d.b.) and reduced to 85.85% with further increase in moisture content upto 30.90% (d.b.).

The initial increase of sphericity could be due to relatively proportional increase in length, width and thickness. However, beyond second moisture content there was relatively greater increase in length as compared to width and thickness which might probably resulted in slight reduction in sphericity (Zewdu and Solomon 2008). Previous studies for other grains had indicated that sphericity could be affected by moisture content in different ways. An increase in the sphericity with increase in moisture content was observed for fenugreek seeds (Altuntas et al. 2005) and arecanut kernel (Kaleemullah and Gunasekar 2002). An initial increase in sphericity upto 20% of moisture content and a decrease with further increase in moisture content was reported for okra seed (Sahoo and Srivastava 2002). This indicates that different grains might behave differently in terms of the relative changes in length, width and thickness which could affect sphericity. The sphericity and the moisture content of the lathyrus could be correlated as.

NLK-40	$\Phi = 86.21 + 0.153 M - 0.006 M^2$	$(R^2 = 0.904)$	(9)
Pratik	$\Phi = 88.57 - 0.048 M - 0.002 M^2$	$(R^2 = 0.996)$	(10)
Ratan	$\Phi = 86.01 + 0.294 M - 0.009 M^2$	$(R^2 = 0.896)$	(11)

where,

Φ sphericity, % and

M moisture content, % (d.b.).

Bulk density A linear decreasing trend was observed in values of bulk density as shown in Fig. 1(c). The values of bulk density of NLK-40, Pratik and Ratan were found decreased from 827.5 to 697.2, 851.3 to 726.3 and 856.0 to 727.4 kg/m^3 with corresponding increase in moisture contents of 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.), respectively. The percent decrease in bulk density of these lathyrus grains

Fig. 1 Effect of moisture content on quality parameters of different varieties of lathyrus

were 15.74, 14.68 and 15.01%, respectively. This variation in bulk density with moisture content was significant at 5% level of significance.

The relative reduction in the densities at high moisture content could be attributed to less weight gain

due to the added moisture in relation to the concomitant volumetric expansion of the grain. Similar trend has been observed for pigeonpea (Shepherd and Bhardwaj 1986), gram (Dutta et al. 1988), soybean (Deshpande et al. 1993), sorghum (Mahapatra et al. 2002), chickpea

(Konak et al. 2002), okra seeds (Sahoo and Srivastava 2002), lathyrus (Zewdu and Solomon 2008) and for minor millets (Balasubramanian and Viswanathan 2010). The bulk density was found to bear the following relationship with moisture content.

NLK-40	$\rho_b = 860.2 - 5.572 M$	$(R^2 = 0.982)$	(12)
Pratik	$\rho_b = 877.2 - 5.230 M$	$(R^2 = 0.976)$	(13)
Ratan	$\rho_b = 890.0 - 5.549 M$	$(R^2 = 0.971)$	(14)

where,

ρ_b bulk density, kg/m^3 and
 M moisture content, % (d.b.)

True density The true density values decreased linearly with increase in moisture content as shown in Fig. 1(d). The true density values of NLK-40, Pratik and Ratan were decreased from 1288.3 to 1074.3, 1324.0 to 1118.4 and 1277.7 to 1102.5 kg/m^3 with increase in moisture content from 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.). The percent decrease in bulk density of these grains was 16.60, 15.12 and 13.71%, respectively. The variation in true density with moisture content of lathyrus was significant at 5% level of significance.

The decrease in true density value for the lathyrus grain with increase in moisture content might be attributed to the relatively higher true volume as compared to corresponding mass of the grain attained due to absorption of water. Similar trends were reported for gram (Dutta et al. 1988), soybean (Kulkarni et al. 1993; Deshpande et al. 1993), green gram (Nimkar and Chattopadhyay 2001), chickpea (Konak et al. 2002), cowpea (Yalcin 2006) and for lathyrus (Zewdu and Solomon 2008). The relationship between true density and moisture content could be represented with the following equations.

NLK-40	$\rho_t = 1353 - 9.369 M$	$(R^2 = 0.983)$	(15)
Pratik	$\rho_t = 1392 - 9.109 M$	$(R^2 = 0.995)$	(16)
Ratan	$\rho_t = 1358 - 8.257 M$	$(R^2 = 0.976)$	(17)

where,

ρ_t true density, kg/m^3 and
 M moisture content, % (d.b.).

Porosity The variations in porosity with moisture content are graphically shown in Fig. 1(e). This indicated that the porosity of lathyrus grain increased initially and then

decreased with increase in moisture content. The porosity values increased from 35.7 to 37.7% with increase in moisture content from 7.33 to 13.10% (d.b.) and then decreased to 35.1% with further increase in moisture content upto 30.29% (d.b.) for NLK-40. For Pratik it was increased from 35.4 to 37.6% with increase in moisture content from 6.75 to 12.50% (d.b.) and then decreased to 35.0% with further increase in moisture content upto 29.95% (d.b.) For Ratan it increased from 34.6 to 36.2% with increase in moisture content from 7.90 to 13.60% (d.b.) and then decreased to 34.0% with further increase in moisture content upto 30.90% (d.b.)

The initial increase in porosity value might be due to the higher decrease in true density value than bulk density value. It also indicated that porosity of seeds of different crops could respond differently for changes in the moisture content, which could be attributed to the relative changes in length, width and thickness, and associated bulk and true densities. This observed trend of initial increase and then decrease for different varieties of lathyrus is in conformity with the results reported by Zewdu and Solomon (2008) for lathyrus.

The relationship between porosity and moisture content for different varieties of lathyrus is described by second degree polynomial equations. The results obtained showed that the moisture content and the porosity values of lathyrus grains are poorly correlated.

NLK-40	$\varepsilon = 33.79 + 0.401 M - 0.012 M^2$	$(R^2 = 0.778)$	(18)
Pratik	$\varepsilon = 33.59 + 0.416 M - 0.012 M^2$	$(R^2 = 0.759)$	(19)
Ratan	$\varepsilon = 32.81 + 0.346 M - 0.010 M^2$	$(R^2 = 0.787)$	(20)

where,

ε porosity, % and
 M moisture content, % (d.b.).

Thousand grain weight The linear increase in thousand grain weight with increase in the moisture content was observed as shown in Fig. 1 (f) and this change was significant at 5% level of significance.

The values of thousand grain weight of NLK-40, Pratik and Ratan were found increased from 64.6 to 103.5, 69.1 to 105.3 and 85.3 to 125.6 g with corresponding increase in moisture content from 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.), respectively. The percent increase in thousand grain weight was 60.13, 52.36, and 47.25%, respectively.

Similar results of effect of grain moisture on thousand grain weight have been reported for soybean (Kulkarni et al. 1993), green gram (Nimkar and Chattopadhyay, 2001),

linseed (Selvi et al. 2006), lathyrus (Zewdu and Solomon 2008) and for red bean (Kiani et al. 2008). The relationship between thousand grain weight with and moisture content could be represented by the following equations.

NLK-40	$W_t = 52.48 + 1.687 M$	$(R^2 = 0.999)$	(21)
Pratik	$W_t = 58.72 + 1.557 M$	$(R^2 = 1.000)$	(22)
Ratan	$W_t = 71.47 + 1.751 M$	$(R^2 = 1.000)$	(23)

where,

W_t thousand grain weight, g and

M moisture content, % (d.b.)

Angle of repose The angle of repose showed an increasing trend with moisture content as shown in Fig. 1 (g), and this change was significant at 5% level of significance. The values of angle of repose of NLK-40, Pratik and Ratan were found increased from 28.39 to 35.41, 29.54 to 35.84 and 26.91 to 33.51° with corresponding increase in the moisture content from 7.33 to 30.29, 6.75 to 29.95 and 7.90 to 30.90% (d.b.), respectively. The percent increase in thousand grain weight was 24.72, 21.32 and 24.52%, respectively.

At higher moisture content within the experimental range, grain might tend to stick together resulting in better stability and less flowability, which increases the value of angle of repose. Similar results have been reported for gram (Dutta et al. 1988), soybean (Deshpande et al. 1993), green gram (Nimkar and Chattopadhyay 2001), lentil (Amin et al. 2004), lathyrus (Zewdu and Solomon 2008) soybean (Kibar and Ozturk 2008) and for minor millets (Balasubramanian and Viswanathan 2010). The following general expressions can be used to describe the relationship between moisture content and angle of repose.

NLK-40	$\Theta = 26.20 + 0.306 M$	$(R^2 = 0.992)$	(24)
Pratik	$\Theta = 27.59 + 0.276 M$	$(R^2 = 0.994)$	(25)
Ratan	$\Theta = 24.73 + 0.288 M$	$(R^2 = 0.997)$	(26)

where,

Θ angle of repose, ° and

M moisture content, % (d.b.).

Grain volume The variations observed in grain volume with increase in moisture content are graphically shown in Fig. 1(h). It was observed that the values of volume increased with increase in moisture content and this change

was significant at 5% level of significance. These results are in conformity with the results reported for gram (Dutta et al. 1988) and for soybean (Deshpande et al. 1993; Kibar and Ozturk 2008). The following general expressions can be used to describe the relationship between moisture content and grain volume.

NLK-40	$V = 8.770 + 0.053 M$	$(R^2 = 0.987)$	(27)
Pratik	$V = 11.27 + 0.0678 M$	$(R^2 = 0.978)$	(28)
Ratan	$V = 11.75 + 0.081 M$	$(R^2 = 0.957)$	(29)

Surface area The surface area of lathyrus grains increased linearly with increase in moisture content for all the varieties as shown in Fig. 1 (i). The values were found increased from 54.78 to 62.29 mm²; 70.38 to 79.45 mm² and 73.31 to 84.88 mm² for NLK-40, Pratik and Ratan, respectively with corresponding increase in moisture content. Similar trend has been reported for linseed (Selvi et al. 2006) and for red kidney bean grains (Isik and Unal 2007). The variation of moisture content and surface area can be expressed mathematically as follows:

NLK-40	$S = 52.62 + 0.318 M$	$(R^2 = 0.988)$	(30)
Pratik	$S = 67.66 + 0.407 M$	$(R^2 = 0.974)$	(31)
Ratan	$S = 70.59 + 0.487 M$	$(R^2 = 0.956)$	(32)

Conclusions

The study concludes that the grain size, thousand grain weight, angle of repose, grain volume and surface area increased linearly with increase in moisture content. The bulk and true densities decreased linearly with increase in moisture content. Whereas the sphericity and porosity exhibited an initial increase followed by a decrease with increase in moisture content for different varieties of lathyrus

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