Evaluation of Methods for Expansion Properties of Legume Extrudates

R. T. Patil, J. De J. Berrios, J. Tang, B. G. Swanson

Abstract. *The expansion properties of extrudate such as diameter ratio, sectional expansion index, longitudinal expansion index, specific length, and specific density are used to describe the effect of extrusion processing as well as material parameters. In this study four types of extrudates namely lentil, lentil+starch, whole dry pea+starch, and split dry pea+ starch were evaluated for their expansion properties with N = 50. The effect of number of replicates and progressive values of the statistical parameters like mean, coefficient of variability (CV), standard deviation (SD), and standard error (SE) were compared graphically. It was determined that 30 replicates were sufficient for determining the expansion characteristics of the extrudates. The CV of the extrudates was lower than other engineering materials due to the homogeneity of the sample, obtained as effect of the mixing capacity of extrusion processing. A mathematical relationship* $N = 774.3655 * e^{-5.6479*\left(\frac{e}{V_o}\right)}$ *was developed from the pooled data to predict the number of replicates required for desired CV from the advance estimate with five observations. The determination of specific density by dimensional measurement, as well as bulk density by glass bead displacement, was also compared. For measurement of bulk density, five replicates were found to satisfy low CV condition.*

***Keywords**. Expansion ratio, Extrusion, Physical properties.*

Expansion is one of the most important properties of food products obtained through high temperature, low moisture extrusion cooking. Extrudate expansion is a complex phenomenon which occurs as a consequence of several factors and mechanisms, influenced by feed composition and extrusion processing parameters. Kokini et al. (1992) proposed five major steps to explain the various phases involved in extrudate expansion. Initially, the high shear, pressure, and temperature inside the extruder allow the transformation of the fed flours into viscoelastic melts. The degree of transformation is highly dependent on the extrusion moisture content and extruder operating variables. Nucleation of bubbles within the polymer melt occurs during extrusion, both at sites where small air bubbles or impurities were entrapped during the extrusion process or in the "holes" that represent the free volume of the polymer. These bubbles grow as the melt leaves the extruder die due to a moisture flash-off process, when the high pressure of the superheated steam generated by moisture vaporization at nuclei overcomes the mechanical resistance of the viscoelastic melt. The bubble growth ceases upon cooling, when the viscoelastic matrix become glassy and no longer allows expansion to take place. Expansion promotes dehydration and the development of a desirable crispy texture on the final extrudate. Therefore, expansion related parameters are important to determine the quality of the extruded product. To evaluate the expansion characteristics of extruded food materials, different expansion indices are used. Balandran-Quintana et al. (1998), Liu et al. (2000), Onwulata et al. (2001), and Morales et al. (2002) used only the diameter ratio as expansion index of the extrudate. Whereas, in most other reports the ratio of diameter square, also known as sectional expansion index, was used (Alvarez Martinez, 1988; Patil et al., 1990; Edwards et al., 1994; Bhattacharya et al., 1997; Matthey and Hanna, 1997; Berrios et al., 2004). Additionally, Alvarez et al. (1988) described another approach to expansion indices, by measuring expansion of the extrudate in three dimensions: sectional, longitudinal, and volumetric index. The specific density, bulk density, and specific length were also used as expansion indices by some authors (Edwards, 1994; Ali, 1996; Cabrejas et al., 1999; Liu et al., 2000; Patil et al., 2001, Berrios, 2004). Cronin et al. (2003) reported that extrudates cut from the same lot showed large variation in their expansion properties and indicated that measure of a small number of samples may result in misleading estimation of average value.

The objective of this study was to develop criteria to evaluate the expansion properties of legume extrudates, using four types of extrudates obtained under defined processing conditions and with expansion ranging from low extrudate diameter (<10 mm) to high extrudate diameter (>15 mm). Also, to determine the optimum sample size required to estimate each expansion property.

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Materials and Methods

Materials and Extrusion

Four different extruded food materials namely, lentil, lentil + starch (80:20), whole dry pea + starch (80:20), and split dry pea + starch (80:20) were used to evaluate various methods of expansion properties in the study. The food materials were processed using a Werner & Pfleiderer Continua 37-mm, co-rotating twin screw extruder (Werner & Pfleiderer Corp., Ramsey, N.J.) system operated at 500 rpm and a die temperature of 160°C. The extruder's die block was equipped with two circular dies 3.5 mm in diameter. The extrudates in the form of rods were collected under steady state extrusion conditions and cooled to room temperature for subsequent measurement of their expansion properties.

The moisture content of the extrudates was determined using standard AACC Method 44-15A (Moisture – Air-Oven Methods, AACC, 2000) in a convection oven. The moisture measurements were taken in triplicate.

Expansion Indices

The extruded rods were cut using a sharp razor blade into 5- to 10-cm long pieces. The diameter and length of each piece was measured in five random places with a Vernier digital caliper, and their weight was recorded on an OHAUS four-digit precision balance (Ohaus Corporation, Pine Brook, N.J.). The data for diameter, length, and weight were collected on 50 pieces from each type of extrudate. From these measurements various expansion criteria were estimated as per the definitions given below:

Diameter of the Extrudate

The diameter of the extrudate (D_e) is a measure of the cross section of the extrudate, which is related to expansion. Therefore, the mean diameter of extrudate products can be compared to distinguish between extrudates with higher or lower degree of expansion.

Diameter Ratio

The diameter ratio (DR) is expressed as the ratio of the diameter of the extrudate (D_e) to the diameter of die opening (D_d) on the extruder.

$$DR = \frac{D_e}{D_d} \tag{1}$$

Specific Length

The specific length (SL) of the extrudate is expressed as the linear length of extrudate measured in millimeters (mm), per gram (g) of unit weight.

Specific Density

The specific density of the extrudate is determined by the ratio of the weight in g to the volume in cubic centimeters (cc) of individual pieces of extrudates. The volume was calculated from the measurements taken from the mean diameter and length of extrudates in the form of rods.

Sectional, Longitudinal and Volumetric Expansion Indices

The sectional, longitudinal and volumetric expansion indices of the extrudates were calculated according to the equations developed by Alvarez-Martinez et al. (1988).

Sectional Expansion Index

The sectional expansion index (SEI) of the extrudates was calculated by dividing the cross-sectional areas of the extrudate (D_e) by the cross-sectional areas of the die opening (D_d) and expressed as:

$$SEI = \left(\frac{D_e}{D_d}\right)^2 \tag{2}$$

Longitudinal Expansion Index

The longitudinal expansion index (LEI) is the ratio of the exiting velocity of the extrudate after expansion to its velocity in the die orifice, expressed by the following equation:

$$LEI = \frac{\left[(1 - M_d) * \rho_d * S_d)\right]}{\left[(1 - M_e) * \rho * S_e)\right]} \tag{3}$$

where ρ_d is the melt density at the die (ρ_d = 1400 kg/m^3), ρ is the specific density of the extrudate; S_d and S_e are the cross section of the die insert and cross section of the extrudate (m^2); M_d and M_e are the moisture contents of the melt and moisture content of the extrudate, respectively.

Volumetric Expansion Index

The volumetric expansion index (VEI) is the product of SEI and LEI and therefore indicates the overall expansion of the extrudate in both radial as well as longitudinal direction and it is expressed as:

$$VEI = LEI * SEI \tag{4}$$

Bulk Density

The extruded rods exhibited visible porous surface (small air gaps). Therefore, a glass bead volume displacement method (Berrios, 2007) was used to evaluate the bulk density (BD) of the extrudates. The BD of each extrudate was determined in 10 replications, using 2-mm diameter glass beads as the volume displacement medium. The density of beads was determined using a wide-mouth glass jar (P/N 217299, 6-oz, 180 mL, Millville, N.J.).

The glass jar was filled with beads and the surface was scraped with a spatula to remove excess beads. The weight of beads required was determined using a top loading balance with 0.01-g accuracy (Model 6100, Mettler Instruments Corp., Highstown, N.J.) and the volume of beads was measured using a 500-mL graduated cylinder. The weight and volume measurements were made five times and their values were used to calculate the average density of beads and volume factor in cc/g. Subsequently, 5 g of the extruded samples were cut into short segments of about 1.5 cm for density determination. Glass beads were added to the glass jar to form a thin layer of approximately 1 cm on the bottom. The glass jar with beads was then placed on the Vibra-Flow® Feeder (Homer City, Pa.) apparatus. Under vibration, some cut pieces of extrudates were placed horizontally on top of the beads' layer. Beads were poured in until the pieces were covered. This procedure was repeated to include all remaining pieces of extrudates. Then, enough beads were poured to over fill the glass jar. A spatula was used to remove the excess glass beads from the surface of the glass jar. The contents were left to vibrate for 5 min. The weight of the measuring glass jar along with the beads and extrudate pieces was recorded. The difference in weight between the glass jar filled with beads plus extrudate and with only beads was used to determine the volume displaced by the extrudate pieces. The bulk density was expressed as the ratio of the weight of pieces to their volume in g/cc.

Statistical Analysis of Expansion Indices

Although the extrudate samples, in the form of expanded rods, were collected when the extrusion processing conditions were at a steady state, there was still visibly large variation in their diameter. Hence, we considered taking observations on 50 pieces in each extrudate. The average value and standard deviation for each property was calculated as a function of the number of replications from 2 to 50. This procedure was applied to all extrudates. Since the standard deviation (SD) does not give an estimation of accuracy for the test, the coefficient of variation (CV) was calculated.

$$CV = SD/M \qquad (5)$$

where M is the mean or average of observations.

The indicator of accuracy of mean value is the standard error (SE) of the mean. Therefore, the SE of the mean was also calculated assuming the normal distribution of the replicates.

$$SE = SD/\sqrt{N} \qquad (6)$$

where N is the number of observations.

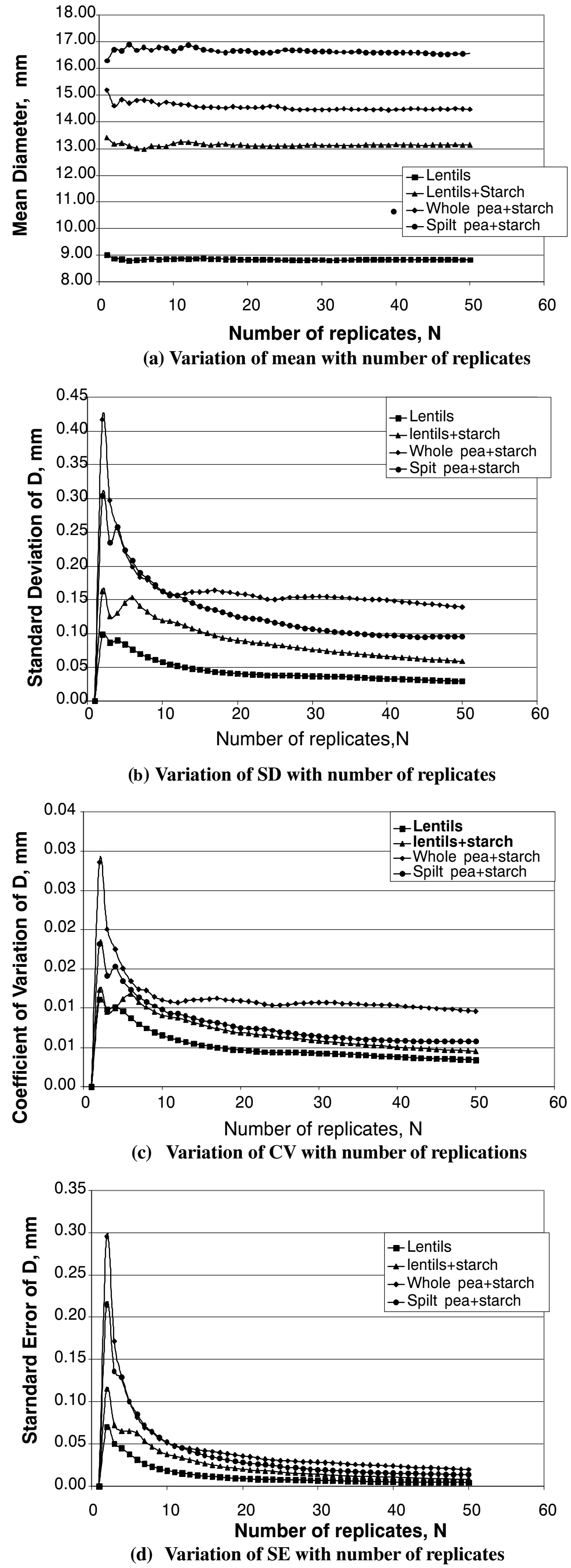
Results and Discussion

The moisture content of the extrudates evaluated in this study varied from 5.84% to 6.92% (wwb). The lentils extrudate had a moisture content of 5.84%, with lentil +starch at 6.95%, Whole peas + starch extrudate at 7.06%, and Split peas and starch extrudate at 6.92% (wwb). The statistical parameters as a function of the number of replicates were computed for each expansion property and the relationship was presented graphically. The typical variation of the statistical parameter for diameter with number of replications is shown in figure 1. The typical variation observed for the mean, standard deviation (SD), coefficient of variation (CV) and the standard error (SE) of the mean are shown in figures 1a-1d, respectively. The optimum number of replications required was considered to be the point at which the variation in CV reached an almost constant level. A similar approach was followed by Hecke et al. (1998) to determine the number of replicates required for puncture tests.

The mean values along with the statistical parameters for the expansion properties of the extrudates are given in table 1.

Diameter of Extrudates and Other Characteristics

Based on the date in figures 1c and 1d it was observed that the CV and SE for diameter in all types of extrudates decreased sharply after about 5 replications and became stable after about 20 replicates. Hence, 20 replications may be sufficient to represent the mean diameter of the extrudate. Similarly, the CV and SE for the most of the other expansion characteristics stabilized after 30 replications.



(a) Variation of mean with number of replicates

(b) Variation of SD with number of replicates

(c) Variation of CV with number of replications

(d) Variation of SE with number of replicates

Figure 1. Typical figures showing the statistical parameters of the mean diameter of the extrudates as a function of the number of replications.

Table 1. Mean values of expansion indices along with their statistical parameters at N = 50.

Expansion Characteristic	Type of Extrudate			
	Lentil	Lentil + Starch	Whole Pea + Starch	Split Pea + Starch
Diameter (mm)				
Mean	8.84	13.14	14.46	16.57
SD	0.03	0.059	0.139	0.095
CV	0.003	0.004	0.009	0.005
SE	0	0	0.001	0
Diameter ratio				
Mean	2.52	3.75	4.13	4.73
SD	0.008	0.016	0.039	0.027
CV	0.003	0.004	0.009	0.005
SE	0	0	0.001	0
Sp. length (mm/g)				
Mean	125.98	86.6	98.63	100.6
SD	1.8	0.963	1.3	3
CV	0.014	0.011	0.013	0.029
SE	0.002	0.001	0.001	0.001
Specific density (g/cc)				
Mean	0.0324	0.022	0.155	0.0117
SD	0.0006	0.0009	0.0002	0.0003
CV	0.018	0.04	0.012	0.025
SE	0	0	0	0
SEI				
Mean	6.37	14.1	17.1	22.45
SD	0.043	0.127	0.329	0.26
CV	0.006	0.009	0.019	0.011
SE	0	0.001	0.002	0.001
LEI				
Mean	5.16	3.69	4.09	4.17
SD	0.073	0.125	0.054	0.124
CV	0.014	0.033	0.001	0.029
SE	0.002	0.004	0.001	0.004
VEI				
Mean	32.88	50.58	69.78	93.02
SD	0.646	1.028	0.727	2.396
CV	0.02	0.02	0.01	0.025
SE	0.091	0.145	0.102	0.338

Specific Density

When similar graphical representations were compared for the statistical parameters of specific density as a function of the number of replicates, it was found that CV and SE became constant at about 30 replications.

Bulk Density

The density of all four types of extrudates was measured by the volume displacement methods (Berrios, 2007) using 10 replications for each extrudate. The graphs for the statistical parameters obtained are shown in figures 2a-2d. It was observed that the value of the statistical parameters reduced with the number of replications and the CV and SE became constant at about five replications.

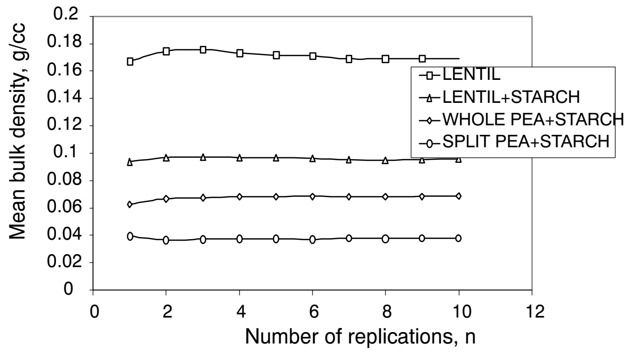
The number of replications required to arrive at a representative value for various expansion properties are shown in table 2.

It was observed that the CV for the expansion property of the extrudates was very low. The CV ranged from 0.34% to 3.1% for 50 replications and from 0.96 to 8.97% for 5 replications. However, in other engineering analyses the CV range was 10% to 15% (*ASTM Standards*, 2000). The ASTM standard E-122-99 (*ASTM Standards*, 2000) for choosing a sample size to estimate quality of a lot or process states that the relationship between the advance estimate of CV and allowable sampling error as a percent of the mean is as follows:

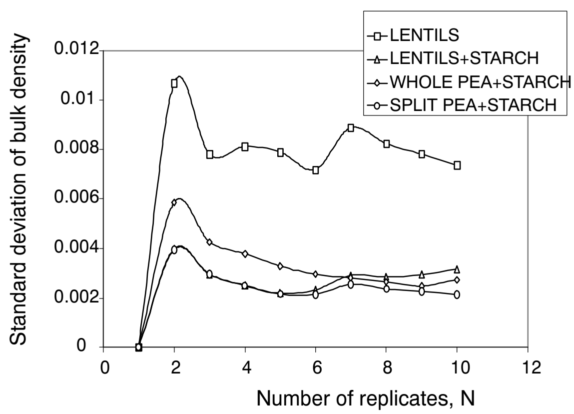
$$n = \left(3\frac{V_0}{e}\right)^2 \quad (7)$$

where n = sample size; V_0 = advance estimate of coefficient of variation expressed as percent of *e* (desired CV). In engineering materials *e* is as high as 10% to 15% based on the materials handled and properties under consideration.

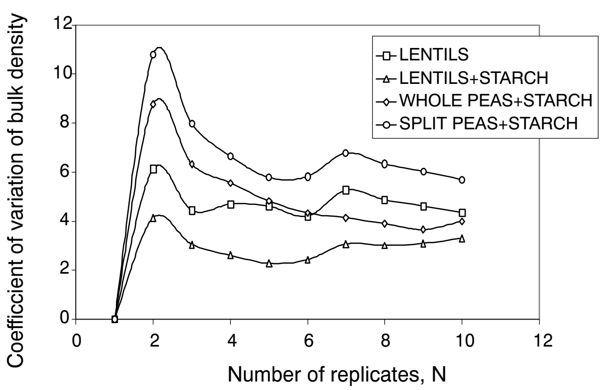
The CV of some of the expansion properties of the legume extrudates found at different sample sizes (number of replications) is given in table 3.



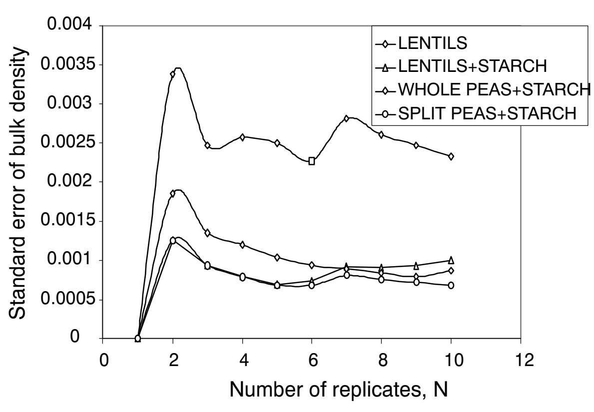
(a) Variation of mean bulk density with number of replicates



(b) Variation in SD with number of replaces



(c)Variation in CV with number of replicates



(d) Variation in SE with number of replicates

Figure 2. Statistical parameters of the BD of the extrudates as a function of the number of replications.

Table 2. No. of replications required for expansion property assessment.

Expansion Characteristic	No. of Replicates
Diameter	20
Diameter ratio	30
Specific length	30
Specific density	30
Sectional expansion index	30
Longitudinal expansion index	30
Volumetric expansion index	30
Bulk density	5

Table 3. Variation of the CV with the number of replications for some important expansion characteristics of the legume extrudates.

		Type of Extrudate			
Expansion Characteristic	Replications	Lentil	Lentil + Starch	Whole Peas + Starch	Split Peas + Starch
Diameter	5	0.96	1.11	1.51	1.34
	10	0.65	0.90	1.11	0.98
	20	0.47	0.67	1.09	0.75
	50	0.34	0.45	0.96	0.58
Specific length	5	1.57	1.69	3.70	8.97
	10	1.11	1.35	2.59	6.28
	20	1.33	1.16	1.82	4.39
	50	1.42	1.11	1.30	3.01
Specific density	5	3.27	6.90	1.53	6.19
	10	2.25	5.80	1.35	4.53
	20	1.88	4.50	1.57	3.16
	50	1.81	4.00	1.23	2.46
Sectional expansion index	5	1.92	2.20	2.97	2.70
	10	1.31	1.79	2.20	1.98
	20	0.94	1.36	2.20	1.52
	50	1.01	0.90	1.93	1.16

Based on the data in table 3, the sample size and CV results are in good agreement with the ASTM E-122-99 method. The V_0 was taken as an advance estimate of CV, which was calculated on the basis of five replications.

In addition to the determination of the variation of the CV (table 3), the average e/V_0 was also determined for the indicated expansion characteristics of the legume extrudates under study (table 4).

The average e/V_0 obtained by progressive calculations at 5, 10, 20, and 50 extrudate replications (table 4), was averaged and fitted to two number of replications equations (N) to generalized the relationship between N and e/V_0 using Sigmaplot 2000 statistical software.

Table 4. Average e/V_0 values for important expansion properties of legume extrudates.

Diameter		Specific Length		Specific Density		Sectional Expansion Index	
e/V_0	N	e/V_0	N	e/V_0	N	e/V_0	N
1.00	5	1.00	5	1.00	5	1.00	5
0.74	10	0.73	10	0.75	10	0.76	10
0.59	20	0.63	20	0.58	20	0.64	20
0.46	50	0.56	50	0.51	50	0.50	50

$$N = a\left(\frac{e}{V_o}\right)^b \quad (8)$$

$$N = a * e^{-b*\left(\frac{e}{V_o}\right)} \quad (9)$$

where N = number of replications, K and L are constants, *e* is the desired CV, and V_0 is the advance estimate at N equal to 5.

The nonlinear regression analysis results for both the equations are shown in table 5.

A typical graph showing the relationship between N and e/V_0 for the expansion extrudate properties of diameter, specific density sectional expansion index, and specific length is presented in figure 3:

A generalized equation based on the best fit relationship of number of replications (N) and ratio of e/V_0 for the expansion properties of legume extrudates under study is given below:

$$N = 774.3655 * e^{-5.6479*\left(\frac{e}{V_o}\right)} \quad R^2 = 0.8777 \quad (10)$$

Since expansion properties are the most important criteria to evaluate the acceptability of expanded extrudate snack-type products, the relationship proposed here can help to determine the number of samples to be evaluated from a given sample lot, based on advance estimate obtained from five replications.

Table 5. Comparison statistics of previous equations.

Equation	R^2	SEE	Coefficient	P
$N = a\left(\frac{e}{V_o}\right)^b$	0.8672	6.7988	A = 4.8159	0.004
			B = -3.2341	0.0001
$N = a * e^{-b*\left(\frac{e}{V_o}\right)}$	0.8777	6.5254	A = 774.3655	0.0354
			B = 5.6479	0.0001

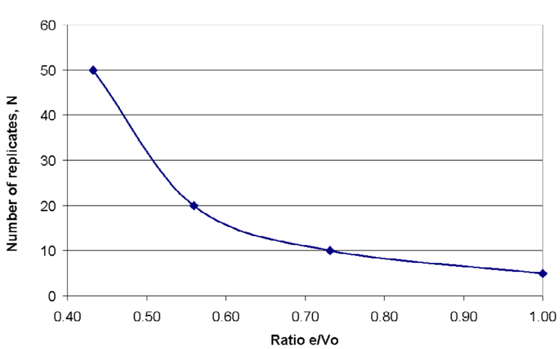


Figure 3. Typical relationship of number of replications (N) and ratio of e/V_0 for some expansion properties of legume extrudates.

Conclusions

From this study the following conclusions are drawn.

- The CV and SE for the most important expansion properties of the extrudates become constant at about 30 replications. This indicates that 30 would be the adequate sample size required for determining the expansion characteristics of the extrudates.
- The mathematical relationship developed between the sample size and ratio of CVs could be accurately used to measure the expansion properties of the extrudates.
- Determination of bulk density based on the volume displacement method demonstrated that only five measurements were sufficient to estimate it, since more than five replications did not significantly change the coefficient of variation.

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References

ASTM Standards. 2000. Standard practice for choice of sample size to estimate a measure of quality for a lot or process. Designation: E 122-99, 27-31. West Conshohocken, Pa.: ASTM.

Ali, Y., M. A. Hanna, and R. Chinnaswamy. 1996. Expansion characteristics of extruded corn grits. *Lebensm.-Wiss.-Technol.* 29(8): 702-707.

Alvarez-Martinez, L., K. P. Kondury, and J. M. Harper. 1988. A general model for expansion of extruded products. *J. of Food Science* 53(2): 609-615.

Balandran-Quintana, R. R., G. V. Barbosa-Canovas, J. J. Zazueta-Morales, A. Anzaldua-Morales, and A. Quintero-Ramos. 1998. Functional and nutritional properties of extruded whole pinto bean meal (*Phaselous Vulgaris* L.). *J. of Food Science* 63(1): 113-116.

Berrios, J. De J. 2007. Evaluation of selected physical properties of extruded legumes: bulk density and pasting property methodologies. Manuscript in preparation.

Berrios, J. De J., D. F. Wood, L. Whitehand, and J. Pan. 2004. Sodium bicarbonate and the microstructure, expansion and color of extruded black beans. *J. of Food Processing and Preservation* 28(5): 321-335.

Bhattacharya, S., P. Chakraborty, D. K. Chattoraj, and S. Mukherjee. 1997. Physico-chemical characteristics of extruded snacks prepared from rice (*Oryza sativa L*) and chickpea (*Cicer arietinum L*) by single screw extrusion. *J. of Food Science and Technology* 34(4): 320-323.

Cabrejas, M., M. A., L. Jaime, C. Karanja, A. J. Downie, M. L. Parker, A. Lopez, J. Francisco, G. Maina, R. M. Esteban, A. C. Smith, and K. M. Waldron. 1999. Modifications to physicochemical and nutritional properties of hard to cook beans (*Phaseolus Vulgaris l.)* by extrusion cooking. *J. of Agricultural and Food Chemistry* 47(3): 1174-1182.

Cronin, K., J. Fitzpatrick, and D. McCarthy. 2003. Packaging strategies to counteract weight variability in extruded food products. *J. of Food Engineering* 56(4): 353-360.

Edwards, R., R. Becker, A. P. Mossman, G. M. Gray, and L. C. Whitehand. 1994. Twin screw extrusion cooking of small white beans (Phaseolus Vulgaris). *Lebensmittel Wissenschaft and Technologie* 27(5): 472-481.

Hecke, E. V., K. Allaf, and J. M. Bouvier. 1998. Texture and structure of crispy-puffed food products, Part II- Mechanical properties in puncture. *J. of Texture Studies* 29(6): 617-632.

Kokini, J. L., C. N. Chang, and L. S. Lai. 1992. The role of rheological properties on extrudate expansion. In *Food Extrusion Science and Technology*, eds. J. L. Kokini, C. T. Ho, and M. V. Karwe, 631-652. New York: Marcel Dekker.

Liu, Y., F. Hsieh, H. Heymann, and H. E. Huff. 2000. Effect of processing conditions on the physical and sensory properties of extruded oat-corn puff. *J. of Food Science*. 65(7): 1253-1259.

Matthey, F. P., and M. A. Hanna. 1997. Physical and functional properties of twin screw extruded whey protein concentrate-corn starch blends. *Lebensm.-Wiss.u.-Technol.* 30(4): 359-366.

Morales, J. Z., F. M. Bustos, N. J. Valenzuala, C. O. Falomir, and O. P. Lopez. 2002. Effects of calcium hydroxide and screw speed on physio chemical characteristics of extruded blue maize. *J. of Food Science.* 67(9): 3350-3358.

Onwulata, C. I., P. W. Smith, R. P. Konstance, and V. H. Hosinger. 2001. Incorporation of whey products in extruded corn, potato or rice snacks. *Food Research International* 34(8): 679-687.

Patil, R. T., K. C. Joshi, S. Gupta, and A. Saran. 2001. Extrusion cooking characteristics of soy-wheat blends to produce ready to eat snacks. *J. of Agricultural Engineering (ISAE)* 37(3): 11-19.

Patil, R. T., D. S. Singh, and R. E. Tribelhorn. 1990. Effect of processing conditions on extrusion cooking of soy rice blend with a dry extrusion cooker. *J. of Food Science and Technology* 27(6):376-378.