Properties of Soybean for Best Postharvest Options

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1. Introduction

Soybean is considered as one very important grain grown commercially in more than 35 countries of the world and the leading producer is the USA (41%) followed by Brazil (23%), Argentina (16%) and China (9%), (F A O 1988).

Soybean contains 40% protein, 35% total carbohydrate and 20% cholesterol-free oil (Deshpande et al., 1993). Mineral content of whole soybean is about 1.7% for potassium, 0.3% for Magnesium, 110 ppm iron, 50 ppm zinc and 20 ppm copper (Smith and Circle, 1972). Soybean is the world leading vegetable oil and accounts for about 20 to 24% of all fats and oil in the world. Soybean is becoming increasingly important in agriculture because it is a food source in human and animal nutrition.

So many varieties have been developed around the world considering desired traits. The properties of the developed cultivars could be considered to vary from one cultivar to the other. Sometimes, such variations in properties (especially physical properties) are easily observable, especially in the size and shape of such cultivars. Other properties would have to be measured to know them or to see how they vary from one cultivar to another. By extension, the properties (physical, mechanical and chemical) of a cultivar affect the post harvest options to which a cultivar may be subjected. The challenge of post harvest processing of soybean into animal and human food is increasing by the day. This is so because, the world’s population is increasing and the challenge of eradicating hunger and producing quality food on the surface of the earth is staring.

Manuwa (2000, 2007), Manuwa et al. (2004, 2005) reported on similar improved varieties of Soybean that were developed in Nigeria. The major improvements made on soybean varieties from 1987 through 1992 at IITA were to increase grain yield by about 20%, improve resistance to pod shattering and to maintain the level of all other traits constant. In order to design equipment for threshing, winnowing, separation, grading, sorting, size reduction, storage, and other secondary processing of soybean, especially the new improved cultivars, the physical properties should be determined.

2. Varieties of soybeans

So many varieties of soybean have been developed around the world so that it is a major task to know all of them. The main aim of developing varieties (cultivars) was to improve desired traits such as:
- Early maturity,
- Disease resistance e.g. phytophthora root rot resistant
- High grain yield,
- Shattering and lodging resistant,
- Intact seed coat and some weathering tolerance,
- Seed quality that meets culinary market standards, for example a light hila culinary type.

A number of varieties have been reported in literature (Tables 1, 2, 3).

3. Harvesting and utilisation of soybean

Needless to say that before soybean can be utilised as food for either man or animal, it must first of all be harvested from the field. However, harvest management is a crucial skill for the specialty soybean producer, simply because the physical appearance of the beans is so important to the buyer. Small-seeded soybeans tend to thresh well, but air adjustments may have to be fine-tuned to remove chaff without blowing the small seeds out the back of the combine. Large-seeded soybeans are extremely prone to mechanical damage during threshing operations, which can knock off the seed coat and/or split the embryo into its cotyledonal halves. The combine’s cylinder speeds will have to be slowed considerably to avoid this, and the crop may require harvesting at somewhat higher moisture content. Prompt harvesting will always be a must, as field deterioration of the seed affecting appearance can commence soon after the moisture content of the physiologically mature seed drops to 14%. If storage is necessary, the producer will have to ensure that storage facilities are clean, dry, and free from any materials that may be toxic to humans. The conditions under which beans are stored greatly influence the quality of the processed product. Moisture content of 13% or less will prevent mold growth. However, very dry beans tend to split when being transferred, and the splitting lowers the quality.

Soybeans can be used for oil, livestock feeds and for preparing various dishes. A number of traditional foods have been produced from soybeans: Tofu, Miso, Natto, Tempeh, Soymilk, Soyflour, Soyoil, soy milk (Bschmann, 2001). According to the report, the size of the seed is often crucial, and may be either smaller or larger than average soybean cultivars. For example, small seeds are sought out for natto, while large seeds are preferred for tofu. Perfectly round seeds are generally prized, while oblong or kidney-shaped soybeans are usually avoided.

4. Post harvest options

Post harvest options are generally all the activities that can be carried out after the harvesting of crops in order to convert it to use by man and animal. It can be classified into primary and secondary processing.

**Primary processing:** This includes threshing, winnowing, cleaning, separation, grading, sorting, packaging, transportation, marketing, storage and so on.

Grains or seeds from harvesters are not directly suitable for its final use such as re-sowing, animal feed or human consumption. The standards of seeds in the three categories have risen in the last few decades to date. Reasons, especially for re-sowing seeds include the need to achieve international marketing standard, and secondly the uniform, high germination product required in precision drilling.
| COUNTRY          | VARIETY       | YIELD (Kg/ha) | SOURCE                                      |
|------------------|---------------|---------------|---------------------------------------------|
| USA              | Jim           | -             | [www.ag.ndsu.nodak.edu/aginfo/variety/soybean.htm](http://www.ag.ndsu.nodak.edu/aginfo/variety/soybean.htm) |
|                  | Traill        | -             |                                             |
|                  | RG200RR       | -             |                                             |
|                  | Walsh         | -             |                                             |
|                  | MN0201        | -             |                                             |
|                  | MN0302        | -             |                                             |
|                  | Barnes        | -             |                                             |
|                  | Normatto      | -             |                                             |
|                  | Nannonatto    | -             |                                             |
|                  | Norpro        | -             |                                             |
|                  | SD1081RR      | -             |                                             |
|                  | Sargent       | -             |                                             |
|                  | Surge         | -             |                                             |
|                  | SD1091RR      | -             |                                             |
| AUSTRALIA        | Arunta        | 3.81          | Adapted from: [www.ag.ndsu.nodak.edu/aginfo/variety/soybean.htm](http://www.ag.ndsu.nodak.edu/aginfo/variety/soybean.htm) |
|                  | Stephens      | 3.80          |                                             |
|                  | Bowyer        | 3.55          |                                             |
|                  | Curringa      | 3.73          |                                             |
|                  | Djakal (BAF 212) | 3.93      |                                             |
| SLOVENIA         | Aldama        | 1791          | Acko and Trdan (2009)                      |
|                  | Borostyan     | 1242          |                                             |
|                  | Essor         | 2757          |                                             |
|                  | Ika           | 3138          |                                             |
|                  | Kador         | 3702          |                                             |
|                  | Major         | 2342          |                                             |
|                  | Nawiko        | 2748          |                                             |
|                  | Olna          | 2272          |                                             |
|                  | Tarna         | 3381          |                                             |
|                  | Tisa          | 4216          |                                             |
| NIGERIA          | Samsoy 2      | 1745          | Manuwa, 2005; 2007                         |
|                  | TGx 923-2E    | 1736          |                                             |
|                  | TGx 992-22E   | 1642          |                                             |
|                  | TGx 1440-1E   | 1629          |                                             |
|                  | TGx 1448-2E   | 1558          |                                             |
|                  | TGx 1660-19F  | 2134          |                                             |
|                  | TGx 1489-1D   | 2071          |                                             |
|                  | TGx 1447-2D   | 1970          |                                             |
|                  | TGx 1437-1D   | 1877          |                                             |
|                  | TGx 1455-2E   | 1660          |                                             |
|                  | TGx 849-313D  | 1524          |                                             |

Table 1. Some Soybean cultivars from USA, Australia, Slovenia & Nigeria
| COUNTRY | VARIETY          | YIELD (Kg/ha) | OIL CONTENT (%) |
|---------|-----------------|--------------|-----------------|
| INDIA   | Alankar         | 2200         | -               |
|         | Ankur           | 2300         | -               |
|         | Clark - 63      | 1800         | -               |
|         | PK-1042         | 3300         | -               |
|         | PK-262          | 2800         | -               |
|         | PK-308          | 2600         | 20-23           |
|         | PK-327          | 2300         | -               |
|         | PK-416          | 3200-3800    | 41-56           |
|         | PK-564          | 3000         | -               |
|         | Shilajeeth      | 2200         | -               |
|         | Bragg           | 1800         | -               |
|         | Calitur         | 1800         | -               |
|         | Durga           | 2100         | -               |
|         | Gaurav          | 2200         | -               |
|         | Indira Soya     | 2300         | -               |
|         | Indira Soya -9  | 2300         | -               |
|         | JS-2            | 1800         | -               |
|         | JS-71-05        | 2000-2400    | 41              |
|         | JS-75-46        | 1600-3100    | -               |
|         | JS-76-205       | 1600-2000    | -               |
|         | JS-79-81        | 2800         | -               |
|         | JS-80-21        | 2500-3000    | -               |
|         | JS-90-41        | 2500-3000    | -               |
|         | JS-333          | 2500-3000    | 17-19           |
|         | MACS-13         | 2700         | 15-22           |
|         | MACS-58         | 2000-2500    | -               |
|         | MAUS-47 (Parbhani ona) | 2500-3000 | 20 |
|         | MS-335          | 2800         | -               |
|         | NRC-12(Ahilya-2) | 2800   | -               |
|         | NRC-2(Ahilya-1) | 3500-4000    | 21              |
|         | NRC-7(Ahilya-3) | 3200         | -               |
|         | PK-472          | 3300         | -               |
|         | PUSA-16         | 2800         | -               |
|         | PUSA-22         | 2600         | -               |
|         | PUSA-37         | 2800         | -               |
|         | TYPE-49         | 2200         | -               |
|         | MACS-57         | 2800         | -               |
|         | MACS-450        | 2500         | 20              |
|         | MAUS-2          | 2450         | -               |
|         | MAUS-1          | 2800         | -               |
|         | MAUS-32(Prasad) | 3000-3500    | 19              |
|         | KB-79(Sneha)    | 1700         | -               |
|         | MACS-124        | 2500-3200    | -               |
|         | PUSA-40         | 2600         | -               |

Source: http://agmarknet.nic.in/soybean-profile.pdf

Table 2. Some Soybean cultivars from India
| BR 16 | BR 36 | BRS 153 | BRS 155 | Embrapa 1 |
|-------|-------|---------|---------|-----------|
| Embrapa 48 | FT 106 I | FT 109 I | FT 2 | FT 20 (Jau) |
| FT 4 | FT 7 (Taro) | FT 9 (Inae) | FT Manaca | FT Seriema |
| IAC 13 | IAC 15 | IAC 15-1 | IAC 16 | IAC 4 |
| IAC Foscarin-31 | IAC/Holambra twart-1 | KI-S 601 | KI-S 602 RCH | MS/BR 34 (Empaer 10) |
| Ocepar 10 | Ocepar 16 | Ocepar 4 (Iguaçu) | Ocepar 7 (Brilhante) | Ocepar 8 |
| RB 502 | BR 9 (Itaúba) | BR 156 | IAC 11 | Paraná |
| BRS 157 | BRSM Apaiari | CEP 12 (Cambará) | Cobb | FT 103 |
| FT 104 | FT 2000 | IAS 4 | Ivorá | Ocepar 17 |
| Ocepar 5 (Piquiri) | RS 5 (Esmeralda) | BRS 134 | BRS 136 | BRS 138 |
| BRS 65 | BRS 66 | BRSM Sambaiba | BRSM Seridó RCH | BRSMG Confiança |
| BRSM Piapara | BRSM Piranjuba | CEP 20 (Guajuvira) | DM Nobre | Embrapa 30 (V. R Doce) |
| Embrapa 62 | Emgopa 313 (Anhang.) | Emgopa 316 (Rio Verde) | FT 101 | FT 19 (Macacha) |
| GO/BR 25 (Aruanã) | IAC 100 | IAC 12 | MS/BR 19 (Pequi) | Ocepar 14 |
| Santa Rosa | BR 28 (Seridó) | BR 38 | BRSM Carla | RB 603 |
| RB 604 | DM 247 | DM 339 | BR 6 (Nova Bragg) Bragg(3) | Bragg |
| BRS 137 | BRS 154 | BRS Celeste | BRSMG Garantia | BRSMG Robusta |
| BRSMG Segurança | BRSMG Virtuosa | BRSMS Mandi | Embrapa 20 | (Doko RC) |
| Embrapa 63 (Mirador) | Emgopa 315 (R. Verm.) | FT 10 (Princesa) | FT 18 (Xavante) | FT 6 (Veneza) |
| FT Cometa | IAC 18 | IAC 22 | MG/BR 48 (Gar. RCH) | |
| UFV 19 FT | UFV/ITM-1 | BR 30 | BRS 135 | BRS Milena |
| BRSM Carandá | BRSM Lambari | BRSM Pirapatanga | BRSM Taquari | BRSMS Tuitui |
| DM Soberana | Embrapa 64 (Ponta Porã) | Emgopa 301 | FT 14 (Piracema) | FT 5 (Formosa) |
| FT Abyara | FT Maracajú | FT Saray | Fundacep 33 | Ocepar 12 |
| UFV 10 (Uberaba) | Bossier | BR IAC 21 | BRSM Parnaiba | BRSMG 68 (Vencedora) |
| BRSMG Liderança | BRSMG Renascença | BRSMs Bacuri | BRSMs Surubi | DM Vitória |
| FT 11 (Alvorada) | FT Guaira | IAC 17 | IAC 8 | IAC 8-2 |
| KI-S 702 | KI-S 801 | MG/BR 46 (Conquista) | Ocepar 3 (Primavera) | UFV 18 (Patos de Minas) |
| BRSGO Goiataba | BR 4 | BR 9 (Savana) | BRSM Pati | Embrapa 4 |
| Embrapa 46 | Embrapa 47 | Emgopa 304 (Campeira) | Emgopa 309 (Goiana) | FT 8 (Araucária) |
| FT Bahia | FT Cristalina | FT Cristalina CH | FT Estrela | FT Iramaia |
| FT Lider | Ivaí | MT/BR 50 (Parecis) | MT/BR 51 (Xingu) | MT/BR 53 (Tucano) |
| Planalto | UFV 5 | BRSM Crixás | CAC-1 | CS 301 |
| CS 303 | DM 118 | Dourados | FEPAgro-RS 10 | FT 102 |
| IAC 20 | M-SOY 2002 | BRSGO Catalão | Campos Gerais | Embrapa 9 (Bays) |
| Emgopa 308 (S.Dourada) | FT 100 | FT 45263 | FT Canarana | FT Eureka |
| IAC 14 | Invicta | Ipagro 21 | RS 7 (Jacuí) | Emgopa 303 |

Adapted from: Glass et al. (2006)

Table 3. Some Soybean cultivars from Alabama, USA
Requirements for seed cleaning:

- To obtain graded lots of seed which will meet home and international testing standards for the variety under consideration, in terms of purity, viability, vigour and size variation.
- To remove completely any seeds, the sale of which in a batch may contravene the Noxious Weeds Act, of some countries.
- To avoid any loss of good seeds in the cleaning process.
- To avoid excessive wear that may be due to sorting machines.
- To remove all contaminants that is capable of damaging subsequent processing machinery such as size reduction machines. Typical contaminants include weed seeds, straws, leaves, stones and soil particles.

Principles of separation:
It is important to identify differences in the physical properties of the seeds and the contaminants that will enable the machine (to be designed) make them flow in different directions. Such properties include the following:

- Seed dimensions: length, width, thickness, geometric mean diameter
- Specific gravity
- Falling rate (float)
- Surface texture, friction
- Colour
- Resilience (ability to bounce)
- Electrical conductance

Typically, most processing machines identify differences in properties between good seeds and contaminants. For example a sieve identifies size while other machines identify a combination of properties such as specific gravity table. The shaking table for example identifies friction, size and density of the seeds. The air-screen cleaner for example make use of differences in size, shape and density of the seeds and such machine range from a small, one fan, single screen machine to the large multi-fan eight screen machine with several air columns. Other machines that are used for primary processing include threshing machine, from simple hand operated threshers to high capacity multi cop threshers, combine harvesters, winnowers, air-screen separators (oscillating or vibrating), graders (band, spiral), separators (spiral, table, magnetic, electrostatic, colour, pneumatic, and so on).

Secondary crop processing: It involves processing of food for direct consumption. This requires grinding, milling, oil extraction and so on. To accomplish these, machines are used such as size reduction machines such as milling machines, dehullers, grinding machines, oil press and so on.

5. Methodology for evaluating soybean properties

Sample preparation: Dry mature Soybeans [Glycine max.] are normally used for all the experiments. Before the experiments, the grains were further cleaned by removing those that were physically bad, unhealthy or broken. The moisture content of the grain would be determined using a standard method. Physical properties were determined at the initial moisture content. Thereafter, grain sample of the desired moisture levels were prepared by adding calculated amount of distilled water and sealed in separated polythene bags. The samples would be kept at about 278 °K in a refrigerator for 1 week to enable the moisture to distribute uniformly throughout the sample. Before the commencement of a test, the
required quantity of the grain was taken out of the refrigerator (if kept there to cool), and allowed to warm up to room temperature at about 305 °K.

**Physical properties:** The physical properties of Soybean to be determined include linear dimensions, mass, bulk density, seed density, volume, surface area, sphericity, porosity, coefficient of static friction on structural surfaces and angle of repose, angle of internal friction, terminal velocity. Experiments were conducted at five levels of moisture content in the desired range and replicated five times. Average values were normally reported. The choice of the range of moisture content was due to the fact that the lower limit was the safe storage moisture content, and the upper range, the maximum moisture content obtainable after the seeds were soaked overnight.

**Linear dimensions and geometric mean diameter:** To determine the size of the grain, 10 sub samples each consisting of 100 grains were randomly taken. From each sub sample, 10 grains were taken and their three linear dimensions namely, length (L), width (W) and thickness (T) were measured with a venier calipers having accuracy of 0.01mm. The geometric mean diameter (D\textsubscript{GM}) of the grain was calculated by using the following relationship (Sreenarayanan et al 1985, Sharma et al 1985).

\[
D_{GM} = (LWT)^{1/3} \tag{1}
\]

**Test weight:** Sub samples of One, one hundred and one thousand soybean grains from each sample were randomly selected and weighed. The averages of the replicated values are usually reported.

**Bulk and seed density:** A method similar to that reported by Shephered and Bhardwaj (1986) can be used to determine the bulk density at each moisture level: a 180 ml cylinder was filled continuously from a height of about 15 cm. Tapping during filling was done to obtain uniform packing and to minimize the wall effect, if any. The filled sample was weighed and the bulk density of the material filling the cylinder was computed (Shephered and Bhardwaj, 1986; Deshpande and Ali, 1988; Mohsenin, 1970). The seed density of the grain can be determined by the liquid displacement method to determine the seed volume similar to that reported (Shephered and Bhardwaj, 1986; Deshpande and Ali, 1988).

**Sphericity and porosity:** According to Mohsenin (1970), sphericity \(\phi\), was calculated using the formula.

\[
\phi = \frac{(LWT)^{1/3}}{L} \tag{2}
\]

Fractional porosity is defined as the fraction of space in the bulk grain which is not occupied by grain. Thompson and Isaacs (1967) gave the following relationship for fractional porosity.

\[
\varepsilon = \frac{(1 - \rho_b)}{\rho_S} \times 100 \tag{3}
\]

where,

- \(\varepsilon\) = fractional porosity
- \(\rho_b\) = bulk density of the seed
- \(\rho_S\) = Seed density

**Angle of repose:** The emptying angle of repose \(\theta\) is normally determined at the moisture levels using the pipe method (Henderson 1982, Jha 1999). A pipe of 40 cm height and 106 mm internal diameter was kept on the floor vertically and filled with the sample, Tapping
during filling was done to obtain uniform packing. The tube was slowly raised above the floor so that the whole material could slide and form a heap. The height above the floor $H$ and the diameter of the heap $D$ at its base were measured with a measuring scale and the angle of reposes $\theta$ of the soybean computer using the equation:

$$\theta = \arctan\left(\frac{2H}{D}\right)$$

**Surface area:** The surface area of the grain can be found by analogy with a sphere of geometric mean diameter for the different levels given by (McCabe et al., 1986)

$$S = \pi D_{GM}^2$$

**Coefficient of static friction:** The coefficient of static friction for seed grain can be determined against structural surfaces such as plywood (with grain parallel to direction of motion and then with grain perpendicular to direction of motion), galvanized steel (GS), glass, concrete and so on. A bottom less wooden box of 150 mm x 150 mm x 40 mm was constructed for this purpose. This was similar to that reported by (Oje, 1994). The box shall be filled with soybean grains on an adjustable tilting surface. The surface would be raised gradually using a screw device until the box started to slide down and the angle of inclination read on a graduated scale.

**Terminal velocity:** The terminal velocity of soybean at different moisture content can be determined using an air column (Polat et al., 2006). For each test, a seed was dropped from the top of a 75 mm diameter, 1 m long glass tube. The air was made to flow upwards in the tube from bottom to the top and the air velocity at which the sample seed was suspended was noted with an anemometer having at least 0.1 m/s sensitivity.

**Angle of internal friction:** To determine the angle of internal friction of soybean at different moisture contents, the direct shear method can be used according to Uzuner (1996), Zou and Brucewitz (2001), Molenda et al. (2002) and Mani et al. (2004). Typical velocity to be used during the experiment is 0.7 mm/min (Kibar and Ozturk, 2008) and the angle of internal friction can be calculated using the following equations:

$$\sigma = \frac{N}{A} \times 100$$

Where: $\sigma$ - normal stress (kPa), $N$ - load applied over sample (kg), $A$ - cellular area (cm²),

$$\tau = \frac{T}{A} \times 100$$

Where: $\tau$ - stress of cutting (kPa), $T$ - strength of cutting (kg),

$$\tau = (C+\sigma \tan \phi)$$

Where: $C$ - cohesion

6. **Rupture force and rupture energy**

To determine the rupture force and rupture energy, a Universal Testing Machine (UTM) can be used such as Instron Universal Testing Machine reported by Tavakoli et al. (2009). It was equipped with a 500 kg compression load cell and integrator. The measurement accuracy was
0.001 N in force and 0.001 mm in deformation. The individual grain was loaded between two parallel plates of the machine and compressed along with thickness until rupture occurred as is denoted by a rupture point in the force-deformation curve. The rupture point is a point on the force-deformation curve at which the loaded specimen shows a visible or invisible failure in the form of breaks or cracks. According to them the point was detected by a continuous decrease of the load in the force-deformation diagram. The loading rate of 5 mm/min was used according to ASAE (2006a). The energy absorbed by the sample at rupture was determined by calculating the area under the force-deformation curve from the relationship:

$$E_a = \frac{F_rD_r}{2}$$  \hspace{1cm} (9)

Where $E_a$ is the rupture energy in mJ, $F_r$ is the rupture force in N and $D_r$ is the deformation at rupture point (Braga et al., 1999).

| Cultivars       | MC range (db) | Dimensions (mm)        | Mass (g)                  | Reference                  |
|-----------------|---------------|------------------------|---------------------------|----------------------------|
| JS-7244         | 8.7-25.0      | L: 6.32 to 6.75        | -                         | Deshpande et al., 1993    |
|                 |               | W: 5.23 to 5.55        | 1000 grains: 110 to 127   |                            |
|                 |               | T: 3.99 to 4.45        |                           |                            |
|                 |               | GMD: 5.09 to 5.51      |                           |                            |
| TGX 1440-1E     | 10.5-34.1     | L: 8.58 to 10.02       | 1 grain: 0.11 to 0.21     | Manuwa, 2000               |
|                 |               | W: 6.51 to 7.22        | 100 grains: 14.67 to 19.98|                            |
|                 |               | T: 5.43 to 5.69        | 1000 grains: 139.18 to 190.6|                           |
|                 |               | GMD: 6.71 to 7.44      |                           |                            |
| TGX 1871-5E     | 7.1-43.7      | L: 7.37 to 9.6         | 1 grain: 0.136 to 0.206   | Manuwa and Afuje, 2004     |
|                 |               | W: 6.48 to 7.45        | 100 grains: 12.3 to 16.59  |                            |
|                 |               | T: 5.33 to 5.54        | 1000 grains: 119.17 to 153.15|                           |
|                 |               | GMD: 6.33 to 7.39      |                           |                            |
| TGX 1019-2EB    | 6.7-47.1      | L: 7.41 to 9.57        | 1 grain: 0.178 to 0.218   | Manuwa and Odubanjo, 2005  |
|                 |               | W: 5.34 to 6.75        | 100 grains: 13.78 to 18.79|                            |
|                 |               | T: 4.54 to 5.17        | 1000 grains: 130.67 to 180.21|                           |
|                 |               | GMD: 5.62 to 6.94      |                           |                            |
| Unspecified     | 6.7-15.3      | L: 7.41 to 9.57        | 1000 grains: 121.76 to 223.65| Polat et al., 2006        |
|                 |               | W: 5.34 to 6.75        |                           |                            |
|                 |               | T: 4.54 to 5.17        |                           |                            |
|                 |               | GMD: 5.62 to 6.94      |                           |                            |
| TGX 1448-2E     | 9.9 to 39.6   | L: 8.3 to 10.4         | 1 grain: 0.19 to 0.24     | Manuwa, 2007               |
|                 |               | W: 6.4 to 7.5          | 100 grains: 15.6 to 19.4   |                            |
|                 |               | T: 5.4 to 5.8          | 1000 grains: 154.2 to 185.6|                            |
|                 |               | GMD: 6.6 to 7.6        |                           |                            |
| Unspecified     | 8-16          | L: 7.24 to 8.19        | NAV                       | Kibar and Ozturk, 2008     |
|                 |               | W: 6.79 to 7.12        |                           |                            |
|                 |               | T: 5.78 to 6.23        |                           |                            |
|                 |               | GMD: 6.57 to 7.14      |                           |                            |
| Unspecified     | 6.92-21.19    | L: 7.27 to 8.23        | 1000 grains: 171.5 to 219.04| Tavakoli et al., 2009     |
|                 |               | W: 6.48 to 6.97        |                           |                            |
|                 |               | T: 5.41 to 5.94        |                           |                            |
|                 |               | GMD: 6.34 to 6.98      |                           |                            |

MC= moisture content, NAV= not available

Table 4. Effect of moisture content on mass and dimensional properties of some soybean cultivars
Table 5. Effect of moisture content on density, sphericity, porosity and terminal velocity of some soybean cultivars

| Cultivars      | MC range (%db) | Seed density | Bulk density | Sphericity (%) | Porosity (%) | Vt (m/s) | Reference          |
|----------------|----------------|--------------|--------------|----------------|--------------|----------|--------------------|
| JS-7244       | 8.7-25.0       | 1216-1124    | 735-708      | 80.6-81.6      | 40-37        | NAV      | Deshpande et al., 1993 |
| TGX 1440-1E   | 10.5-34.1      | 1184-1076    | 720-631      | 79-73.3        | 23.6-34.2    | NAV      | Manuwa, 2000        |
| TGX 1871-5E   | 7.1-43.7       | 1222.3-935.7 | 686.5-616.7  | 85.87-78.23    | 25.64-40.96  | NAV      | Manuwa and Afuye, 2004 |
| TGX 1019-2EB  | 6.7-47.1       | 1157-952     | 728.5-608.4  | 86-74.9        | 23.46-42.33  | NAV      | Manuwa and Odubanjo, 2005 |
| Unspecified   | 6.7-15.3       | 1062.6 to 1086.5 | 804.8 to 689.3 | 75 to 72     | 51 to 44.2  | 7.13 to 9.24 | Polat et al., 2006 |
| TGX 1448-2E   | 9.9 to 39.6   | 1465-1074    | 714-638      | 79.1-72.7      | 19.5-33.7    | NAV      | Manuwa, 2007        |
| Unspecified   | 8-16           | 983.33-905.67 | 766.12-719.00 | 91-87       | 22.58-20.61 | NAV      | Kibar and Ozturk, 2008 |
| Unspecified   | 6.92-21.19     | 1147.86 to 1126.43 | 650.95 to 625.36 | 87.25 to 84.75 | 43.29-44.48 | NAV      | Tavakoli et al., 2009 |

MC = moisture content, NAV = not available
Vt = terminal velocity

Table 6. Effect of moisture content on angle of repose and coefficient of static friction of some soybean cultivars

| Cultivars      | MC range (%db) | Angle of repose (degree) | Coefficient of static friction | Reference |
|----------------|----------------|--------------------------|-------------------------------|-----------|
|                |                | Galvanised steel         | PWLG                          | PWDG      | Glass |                   |
| JS-7244        | 8.7-25.0       | 24.1 - 31.5              | 0.344 - 0.509                 | 0.446 - 0.600 | 0.481 - 0.653 | -         | Deshpande et al., 1993 |
| TGX 1440-1E    | 10.5-34.1      | 23.43 - 32.23            | 0.434 - 0.679                 | 0.4245 - 0.601 | 0.4243 - 0.6789 | -         | Manuwa, 2000          |
| TGX 1871-5E    | 7.1-43.7       | 25.87 - 32.45            | 0.3839 - 0.5774               | 0.4877 - 0.6249 | 0.4922 - 0.6876 | NAV      | Manuwa and Afuye, 2004 |
| Unspecified    | 6.7-15.3       | 24.56 - 29.93            | 0.28 - 0.326                  | 0.287 - 0.361 | 0.262 - 0.307 | -         | Polat et al., 2006    |
| TGX 1448-2E    | 9.9 to 39.6   | 24.2 - 30.2              | 0.391 - 0.510                 | 0.466 - 0.601 | -      |                   | Kibar and Ozturk, 2008 |
| Unspecified    | 8-16           | 0.164 - 0.286            |                               |           |       |                   |                      |
| Unspecified    | 6.92-21.19     | 24.56 - 29.93            | 0.28 - 0.326                  | 0.287 - 0.361 | 0.262 - 0.307 | Tavakoli et al., 2009 |

MC = moisture content, NAV = not available, PWLG = plywood parallel to grain, PWDG = plywood perpendicular to grain *PLWD = plywood

Table 6. Effect of moisture content on angle of repose and coefficient of static friction of some soybean cultivars
7. Estimated values of soybean properties

Some typical values and models of physical, mechanical and aerodynamic properties of soybean cultivars are reported in this section (Tables 4 to 6). Table 4 shows the effect of moisture content on mass and dimensional properties of some soybean cultivars. Table 5 shows the effect of moisture content on density, sphericity, porosity and terminal velocity of some soybean cultivars. Table 6 shows the effect of moisture content on angle of repose and coefficient of static friction of some soybean cultivars.

8. General comments

It can be seen that the number of soybean cultivars that have been developed around the world is numerous and can be better imagined. However, it appears that very little has been reported in literature concerning physical and engineering properties of such soybean cultivars. Nevertheless, it is obvious that post harvest options or technology are *sine qua non* in order to convert soybean seeds into quality food for human and animal in view of the quality of food nutrition available in the seeds.

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Worldwide, soybean seed proteins represent a major source of amino acids for human and animal nutrition. Soybean seeds are an important and economical source of protein in the diet of many developed and developing countries. Soy is a complete protein and soyfoods are rich in vitamins and minerals. Soybean protein provides all the essential amino acids in the amounts needed for human health. Recent research suggests that soy may also lower risk of prostate, colon and breast cancers as well as osteoporosis and other bone health problems and alleviate hot flashes associated with menopause. This volume is expected to be useful for student, researchers and public who are interested in soybean.

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