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Development of seed shape software 'SEEDFIG' and study of seed size and seed shape traits in soybean (Glycine max [L.] Merr.)

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Abstract
Soybean is one of the most important crops in the world. Plant breeders' primary focus while attempting to increase soybean production is on characteristics that affect yield. This is because characteristics relating to seed size and shape play a key role in determining seed weight and yield in soybean. Seed appearance, quality, and yield in soybeans are determined by traits related to seed size, such as seed length (SL), seed width (SW), and seed height (SH); seed volume (SV); and seed shape traits, such as seed length to width ratio (SLW), seed length to height ratio (SLH), and seed width to height ratios (SWH). In this study, we discovered that among the 25 soybean genotypes evaluated, there were notable differences in the characteristics of seeds, including SL, SW, SH, SV, SLW, SLH, SWH, and 100SW. Ten varieties of soybeans were reported to be larger (> 14 g/100 seeds), while fifteen were medium-sized (13.99 g/100 seeds). In this study, six round genotypes and nineteen elliptical genotypes of soybean were reported. The results of this study open up the possibility of choosing parents with acceptable traits for hybridization and breeding projects aimed at soybean genetic improvement.

Keywords: Soybean, seed size, seed shape and yield

Introduction
One of the most significant crops in the world is soybean. Because of its great nutritional content, it is employed in both human and animal feeding. Plant breeders' primary focus while attempting to increase soybean production is on characteristics that affect yield. This is because characteristics relating to seed size and shape play a key role in determining seed weight and yield in soybean (Salas *et al.*, 2006; Yan *et al.*, 2011) [1, 2]. The appearance, quality, and yield of soybean seeds are determined by seed size traits, including seed length (SL), seed width (SW), and seed height (SH), seed volume (SV) as well as seed shape traits, including seed length to width ratio (SLW), seed length to height ratio (SLH), and seed width to height ratio (SWH) (Xu *et al.*, 2011) [3]. The environment (E) and genotype x environment (G x E) interactions have a significant impact on seed size and shape, which are complicated quantitative features mediated by polygenes (Hu *et al.*, 2013) [4].
Additionally, seed size and shape have a significant role in determining the specific soy-based foods produced from soybean (Gandhi, 2009). For instance, small-seeded cultivars are best for making sprouts and fermented soybeans (natto), but large-seeded cultivars are used to make soymilk, green soybeans (edamame), boiled soybeans (nimame), and soybean curd (tofu) (Liang *et al.*, 2016; Teng *et al.*, 2017) [6, 7]. Through selective breeding, high-yielding soybean varieties with large seeds or soybean types with small seeds for natto and sprouts can be created. This entails choosing local varieties, old varieties, new varieties, and introduced materials to serve as parents for the hybridization process. Artificial crossings between chosen parents with distinct traits are used to create populations, and then various breeding techniques are used to create elite lines. To produce soybean cultivars for yield and particular objectives, genetic factors relating to seed size and shape are crucial. In this regard, this study was undertaken to study the seed size and seed shape traits in vegetable and seed type soybean.

Materials and Methods
Development of seed shape software 'SEEDFIG'
Seed shape is a crucial feature because it links to genetic, physiological, and ecological components and has an impact on yield, quality, and market price.

To ascertain the shape of various vegetable and soybean genotype seeds, the seed shape software "SEEDFIG" was created. The back end, which is the server-side of the website, and the front end, often known as the "client side," of the application were created using distinct coding languages. HTML (Hypertext Markup Language), CSS (Cascading Style Sheets), and JavaScript were used to construct the client side of the application. PHP was used in the server-side development of the website.

Plant material and experimental design

25 soybean genotypes were evaluated from July to November 2021, at the Indian Agricultural Research Institute, New Delhi, India. These soybean genotypes included 8 seed-type genotypes and 17 vegetable genotypes. A 40 cm spacing between rows and a 10 cm spacing between plant was used for each line. Three replicates of the experiment were used in a randomised complete block design (RCBD).

Seed preparation

After 90 % of the leaves had turned yellow or dropped, soybean pods were harvested. In order to speed up the spawning process, the harvested pods were then dried in the sun. After getting the seeds, an inspection was done. Seed length (SL), seed width (SW), seed height (SH), and weight of 100 seeds were recorded as seed characteristics (100SW). Digital Vernier callipers were used to measure the length, width, and height of the seeds, and digital weighing machine was used to determine the weight of 100 seeds. The ratio of the seed's length to its width determines the shape of the seed.

Statistical Analysis

The data was statistically analysed using STAR software developed by the International Rice Research Institute, Philippines for analysis of variance. Another software 'SEEDFIG' which was developed in this study was used to determine the seed shape of soybean genotypes. The seed length to width ratio (SLW), seed length to height ratio (SLH), seed width to height ratio (SWH), seed volume (SV), and seed shape were derived using the data of the seed length, width, and height.

Results and Discussion

'SEEDFIG' software for determination of seed shape

For particular soy-based food products including natto, sprouts, soymilk, edamame, nimame, and tofu, among others, seed shape is an important characteristic. Large seeded cultivars are utilised for soymilk, edamame (green soybeans), nimame (boiled soybeans), and tofu, whereas small-seeded cultivars are best for natto (fermented soybean) and sprouts (soybean curd). In this work, we created the software "SEEDFIG" to model seeds (Figure 1). This "SEEDFIG" web-based programme is accessible at http://seedfig.in/. 25 soybean genotypes' seed length, width, and height were utilised as input, and using software, the seed shape determination traits *viz*. seed length to width ratio (SLW), seed length to height ratio (SLH), seed width to height ration (SWH), seed volume (SV) and seed shape were determined (Figure 1).

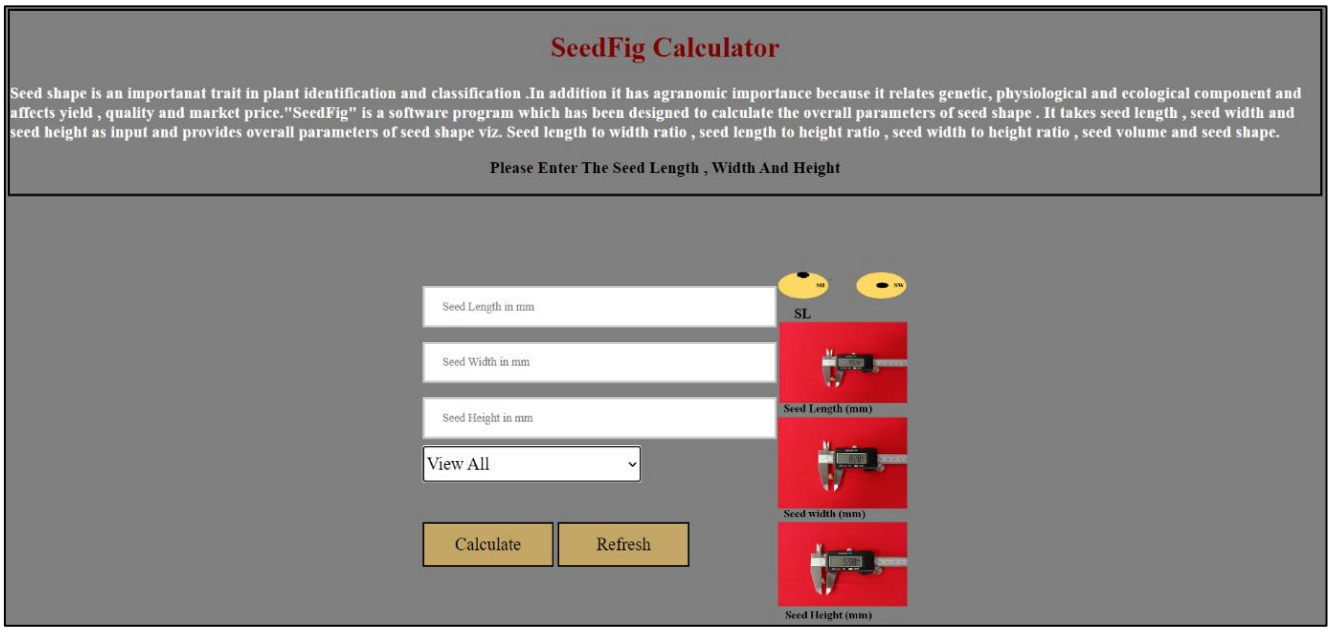

Fig 1: 'SEEDFIG' calculator to determine the seed shapes of soybean.

Diversity in shape and size of soybean seeds

The analysis of variance revealed that the characteristics of seeds, including seed length (SL), seed width (SW), seed height (SH), seed length to width ratio (SLW), seed height to width ratio (SLH), seed width to height ratio (SWH), and weight of 100 seeds (100SW), all differed significantly from one another (Table 1). This demonstrates that all observable features in our investigation were significantly impacted by soybean genotypes. Block impact was not significant for SLW, SLH, and SWH, but it was significant for SL, SW, SH, SV, and 100SW (Table 1). All observed characters have a low coefficient of variation, which suggests that the data from each replication is generally reliable. The ratio of the three seed properties is influenced by variations in seed length, seed width, and seed height. As a result, the 25 soybean genotypes evaluated varied in the size and shape of their seeds (Table 2). Two seed forms were identified based on the length to width ratio of the seeds: round (6 genotypes) and ellipse (19

genotypes). There are two groupings of seed sizes based on the weight of 100 seeds: 10 big seed genotypes (> 14.00 g) and 15 medium seed genotypes (< 13.99 g).

One of the crucial characteristics for the food sector in many nations, including the USA and China, is the shape of soybean seeds (Salas *et al.* 2006; Xu *et al.* 2011) [1, 3]. As a result, selection processes in soybean breeding programmes at abroad place greater emphasis on seed shape than seed size. In early generation populations, seed morphologies can be selected using individual selection techniques. The shape of soybean seeds is a polygenic trait that is regulated by a variety of genes and exhibits stability in a range of conditions (Song *et al.* 2004) [8]. However, soybean producers in the majority of the world are more concerned with seed size than seed shape. One of the characteristics utilised by farmers and the soy-based food industry choose which soybean varieties to grow big size soybean seed. Big size soybean genotypes are preferred by the tofu and tempeh processing industries. Today, numerous breeding initiatives have been undertaken to produce large-seeded soybean types and boost global soybean production. According to our study, the large-seeded soybean group comprises 10 of the 25 genotypes of soybean that were examined (Table 2). In the soybean populations tested, large seeded genotypes were less common than medium seeded genotypes. AGS 292, AGS 329, AGS 346, AGS 465 (30 g/100 seeds), and AGS 457 (32 g/100 seeds) are a few kinds with unusually large seeds. In efforts to boost soybean production, the weight of 100 seeds as an illustration of seed size is crucial (Johnson *et al.* 2001) [9]. It is well established that seed size is inherited genetically and directly affects soybean production in a favourable way (El-Badway and Mehasen, 2012) [10].

Table 1: Analysis of variation of soybean seed characteristics

Source of variation	DF	SL	SW	SH	SV	SLW	SLH	SWH	100SW
Block	2	0.11**	0.07**	0.05**	1886.54**	0.004	0.006	0.003	0.64**
Genotype	24	5.14**	3.07**	1.65**	35536.76**	0.02**	0.1**	0.05**	231.15**
Error	48	0.004	0.001	0.001	176.23	0.003	0.004	0.001	0.03
CD		0.19	0.1	0.09	42.04	0.18	0.21	0.03	0.51
CV (%)		0.87	0.5	0.56	5.34	4.96	4.66	0.81	0.96

Table 2: Seed characteristics of 25 soybean genotypes.

S No	Variety	SL (mm)	SW (mm)	SH (mm)	SV (mm^3)	SLW	SLH	SWH	100SW (g)	Shape
1	AGS 292	8.62	7.86	5.86	397.03	1.10	1.47	1.34	30.00	Ellipse
2	AGS 314	5.40	4.46	3.50	84.20	1.21	1.54	1.27	5.23	Ellipse
3	AGS 329	8.00	7.03	6.62	372.08	1.14	1.21	1.06	30.00	Ellipse
4	AGS 346	9.32	7.75	6.08	439.16	1.20	1.53	1.27	30.00	Ellipse
5	AGS 366	6.51	5.54	4.62	166.31	1.17	1.41	1.20	7.38	Ellipse
6	AGS 457	9.39	7.84	4.57	335.89	1.20	2.06	1.72	32.00	Ellipse
7	AGS 464	8.39	7.49	5.59	350.73	1.12	1.50	1.34	30.00	Ellipse
8	AGS 465	9.53	7.20	5.56	380.96	1.32	1.71	1.30	27.00	Ellipse
9	AGS 471	9.04	7.89	5.86	417.35	1.15	1.54	1.35	26.00	Ellipse
10	Swarna Vasundhara	8.19	6.89	5.54	312.39	1.19	1.48	1.24	23.00	Ellipse
11	AVSB 2004	6.52	6.60	5.36	230.48	0.99	1.22	1.23	13.50	Round
12	AVSB 2005	6.66	6.37	5.23	221.70	1.05	1.27	1.22	12.50	Round
13	AVSB 2006	6.46	6.14	5.47	216.60	1.05	1.18	1.12	12.00	Round
14	AVSB 2007	6.67	6.30	5.54	232.61	1.06	1.20	1.14	20.00	Round
15	AVSB 2009	6.31	6.12	5.27	203.15	1.03	1.20	1.16	12.00	Round
16	AVSB 2010	7.37	6.72	5.76	285.27	1.10	1.28	1.17	13.00	Ellipse
17	AVSB 2012	6.76	6.24	4.80	202.33	1.08	1.41	1.30	13.00	Ellipse
18	SKAF 148	5.73	5.24	4.24	127.31	1.09	1.35	1.24	8.60	Ellipse
19	DS 9712	6.07	5.36	4.48	145.50	1.13	1.35	1.20	8.00	Ellipse
20	JS 335	6.01	5.20	4.46	139.25	1.16	1.35	1.16	15.00	Ellipse
21	JS 20-34	5.39	5.10	3.89	106.83	1.06	1.39	1.31	9.00	Round
22	JS 20-69	6.29	5.62	4.94	174.47	1.12	1.27	1.14	11.00	Ellipse
23	JS 20-98	6.15	5.54	4.57	155.44	1.11	1.34	1.21	10.00	Ellipse
24	JS 20-116	5.98	5.22	4.31	134.41	1.15	1.39	1.21	10.50	Ellipse
25	JS 20-29	6.48	5.56	4.80	172.65	1.17	1.35	1.16	10.50	Ellipse

Conclusion

In this work, seed shape software called "SEEDFIG" was created to identify the soybean seed shape. We discovered that among the 25 soybean genotypes tested in this study, there were significant differences in the characteristics of seeds, including seed length (SL), seed width (SW), seed height (SH), seed length to width ratio (SLW), seed length to height ratio (SLH), seed width to height ratio (SWH), and weight of 100 seeds (100SW). Ten varieties of soybeans were reported to be larger (> 14 g/100 seeds), while fifteen were medium-sized (<13.99 g/100 seeds). In this study, 6 round genotypes and 19 elliptical genotypes of soybean were reported. To create larger seeded types, selection criteria such as length, width, thickness, the ratio of the three features, and the weight of 100 seeds can be used. For the genetic improvement of soybean, hybridization and breeding programmes can select parents with desired traits.

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