

A Sequential Screening Scheme for Selection of Vegetable-Type (Edamame) Soybean: Characterization of Bold-Seeded AVRDC Accessions for Pod, Seed, and Sensory Traits at R6 Stage

Neha Pandey^{1*}, Sanjay Gupta¹, Vangala Rajesh¹, T. Onkarappa², V.S. Bhatia¹

¹ICAR-Indian Institute of Soybean Research, Indore 452 001, Madhya Pradesh, India

²University of Agricultural Sciences (UAS), GKVK campus, Bengaluru, India

*Email: nehapandey.ft06@gmail.com

ABSTRACT

Bold-seeded vegetable-type soybean accessions from AVRDC, Taiwan were characterized at R6 stage (kharif 2018-19; field evaluation at UAS, Bengaluru and laboratory analyses at ICAR-IISR, Indore) for pod, seed, biochemical and sensory traits to derive a practical selection scheme for Indian edamame breeding. Wide variability was recorded (100-pod weight 100-516 g; 100-seed fresh weight 18.1-141 g; TSS 4.0-7.8 °Brix). Principal component analysis (52 accessions) showed pod-and-seed boldness as the dominant axis (44.2% of variation), independent of sweetness. 100-pod weight predicted 100-seed weight ($R^2 = 0.53$), and the non-destructive criterion of 100-pod weight ≥ 300 g with pod length ≥ 5 cm classified bold-seeded lines with 83 per cent accuracy. A four-stage sequential scheme (visual $\rightarrow$ pod boldness $\rightarrow$ TSS ≥ 6 °Brix $\rightarrow$ sensory panel) narrowed 116 accessions to five candidates (EC 916036, EC 916033, EC 915907, EC 916037, EC 916039) recommended for replicated evaluation and hybridization.

Key words: Vegetable soybean, edamame, *Glycine max*, sequential screening, principal component analysis, sensory evaluation

Introduction

Soybean (*Glycine max* (L.) Merr.), domesticated in East Asia (Hymowitz 1970), is consumed in that region not only as processed grain products but also as a green vegetable. Vegetable soybean, popularly known as edamame in Japan, mao dou in China and poot kong in Korea, is harvested at the R6 reproductive stage (Fehr and Caviness 1977), when pods are completely filled but pods and seeds are still green. At this stage the beans are sweeter, more tender, lower in trypsin-inhibitor activity and indigestible oligosaccharides, and richer in vitamins than mature grain soybean (Konovsky et al 1994; Kumar et al 2006). Consumer studies confirm ready acceptance of green vegetable soybean even among consumers unfamiliar with the crop (Young et al 2000; Wszelaki et al 2005), demand is rising worldwide (Rao et al 2002; Zhang and Kyei-Boahen 2007), and consumer perception is now used directly to guide edamame variety development, with sweetness and mild flavour identified as the attributes driving acceptability (Carneiro et al 2020, 2021a, 2021b).

True vegetable soybean is distinguished from immature grain soybean by defined benchmarks: bold seed, pods at least 5 cm long bearing two to three seeds, completely green pods with white and preferably sparse pubescence, ease of cooking, and a slightly sweet, mild, nutty flavour free of beany off-flavour (Shanmugasundaram et al 1991; Konovsky et al 1994; Salas et al 2006). Eating quality is governed largely by sucrose and taste-related free amino acids such as glutamate and alanine (Masuda 1991; Tsou and Hong 1991; Kumar et al 2011; Yu et al 2021). Vegetable soybean is also a rich source of isoflavones, phenols, vitamin C and antioxidant activity at the immature stage (Mebrahtu et al 2004; Moriyama and Oba 2008; Kumar et al 2009, 2010, 2014).

India, where nearly half of children under five are underweight or stunted (UNICEF 2016), stands to benefit from a protein-dense, quick-cooking green legume, and vegetable soybean with protein quality comparable to animal protein has been proposed for improving nutrition (Keatinge et al 2011). The crop remains in its infancy in the country, and commercial production is limited primarily by the absence of adapted vegetable-type cultivars, a constraint reported wherever edamame has been introduced outside East Asia (Duppung and Hatterman-Valenti 2005; Carson et al 2011; Ogles et al 2016; Guo et al 2020); preliminary characterization of introduced AVRDC material and its production prospects under Indian conditions have been outlined earlier (Pandey et al 2019). Parallel food-technology work at ICAR-IISR on reducing the long cooking time of whole soybean (Pandey et al 2017) and on acceptable soy-based value-added products such as eggless fat-reduced mayonnaise (Vasudevan et al 2021), soy-fortified cake (Mathew et al 2021), soymilk-based lassi (Pandey et al 2020), mango-blended soy shrikhand (Pandey et al 2021) and functional soy-protein conjugates (Pandey et al 2026) demonstrates viable utilization pathways for the crop, but fresh-vegetable use ultimately requires adapted, palatable varieties. Earlier in-field organoleptic screening of over two thousand soybean germplasm lines at ICAR-IISR, Indore identified sweetness, tenderness, seed boldness and freedom from off-flavours as basic screening criteria and highlighted the scarcity of bold-seeded sweet lines in Indian germplasm (Pandey 2017); recent characterization of edamame germplasm for food-quality traits in India reinforces this need (Pardeshi et al 2024). Introductions from AVRDC (World Vegetable Center), Taiwan, whose programme has supplied vegetable soybean lines to national programmes worldwide (Shanmugasundaram et al 1991), are a logical

source of such traits, and considerable diversity exists within vegetable soybean germplasm (Dong et al 2014).

Screening large germplasm sets for edamame suitability is, however, laborious if every line must be shelled, analysed and tasted. A practical scheme should therefore be sequential: inexpensive non-destructive criteria applied first to the whole nursery, with destructive and panel-based tests reserved for progressively smaller subsets. The objectives of the present study were (i) to characterize bold-seeded vegetable-type soybean accessions from AVRDC for pod, seed, biochemical and sensory attributes at R6 stage under central Indian conditions, (ii) to quantify the structure of variability and inter-trait relationships using multivariate analysis, and (iii) to derive and demonstrate a stage-wise selection scheme, with data-based thresholds, for identifying promising edamame genotypes for Indian variety development.

Material and Methods

The experimental material comprised 116 bold-seeded vegetable-type soybean accessions (EC 915897-EC 916040 series and allied entries) introduced from AVRDC, Taiwan, raised in an unreplicated germplasm evaluation nursery during kharif 2018-19 at the research farm of the University of Agricultural Sciences (UAS), GKVK campus, Bengaluru (13.08° N, 77.57° E; about 930 m above mean sea level), Karnataka, following recommended agronomic practices. Field observations on pod and plant characters were recorded at Bengaluru, while biochemical determinations and the sensory evaluation described below were carried out on sampled material at ICAR-Indian Institute of Soybean Research, Indore, where pot-grown material was also maintained for confirmatory observations. Since the trial was an unreplicated observational nursery, genotype comparisons rely on descriptive and multivariate statistics rather than analysis of variance; sample-level replication was maintained within each accession for all measured traits.

Green pods were hand-picked at R6 stage (Fehr and Caviness 1977). Pods per plant was recorded on five random plants per accession. Pod length, breadth and thickness (cm) were measured on three random pods; 100-pod weight (g), pod volume (cc, water displacement), peel (pod-wall) weight per pod (g), 100-peel weight (g) and peel thickness (cm) were recorded. Seeds shelled from green pods were measured for seed length, breadth and thickness (cm), seeds per pod, 100-seed fresh weight (g) and seed volume (cc). Moisture content of green seed (%) was determined gravimetrically. Total soluble solids (TSS, °Brix) of macerated green seed were measured with a hand refractometer. Pubescence colour and density were scored visually and coded numerically for multivariate analysis.

A subset of 22 lines meeting visual vegetable-type standards was evaluated organoleptically following the in-field descriptive approach standardized earlier at this institute (Pandey 2017), broadly consistent with quantitative descriptive analysis practice (Stone and Sidel

1993; Armelino et al 2006). Pods were washed, boiled briefly in lightly salted water and served warm; a small trained panel scored softness, sweetness, beaniness and overall taste on a 1-5 intensity scale. Sensory data were treated as a confirmatory stage applied to shortlisted lines and were not included in the multivariate analysis of the full trait set.

For descriptive statistics, all accessions with a valid observation for a given trait were used; missing or evidently erroneous entries (recorded zeros for dimensional traits) were excluded trait-wise, and one data-entry error in pod breadth (12.0 cm) was corrected to 1.2 cm after verification against replicate readings. For multivariate analysis, a complete-case subset of 52 accessions with 15 quantitative traits was used. Traits were standardized before principal component analysis (Hotelling 1933; Jolliffe 2002), retaining components with eigenvalues above one. Hierarchical clustering used Ward's minimum-variance method (Ward 1963) with Euclidean distance (Sneath and Sokal 1973), following standard practice for germplasm diversity analysis (Mohammadi and Prasanna 2003). Pearson correlations were computed among quantitative traits ($n = 52$) and among sensory attributes ($n = 22$). Simple linear regression of 100-seed weight on 100-pod weight was fitted, and the classification performance (sensitivity, specificity, accuracy) of candidate non-destructive thresholds for identifying bold-seeded lines (100-seed fresh weight ≥ 60 g) was evaluated on the 52-accession set. Analyses were carried out in Python (pandas, scikit-learn, SciPy).

Results and Discussion

Variability for pod, seed and biochemical traits

Wide variability was evident for nearly all characters (Table 1). Pods per plant ranged from 13.2 to 71.6 (mean 36.1, CV 32.7%) and 100-pod weight from 100 to 516 g (mean 287 g, CV 28.4%). Pod length averaged 5.08 cm (2.9-7.3 cm), with about half the accessions meeting or exceeding the 5-cm commercial standard, and seeds per pod ranged from 2.0 to 3.0 (mean 2.4), consistent with the accepted edamame pod ideotype (Shanmugasundaram et al 1991; Konovsky et al 1994). Fresh 100-seed weight showed the widest relative spread among seed traits (18.1-141.0 g, CV 33.2%), and green-seed moisture (mean 67.0%) agreed with values reported for vegetable soybean at R6 (Song et al 2003; Kumar et al 2006). TSS varied nearly threefold (3.0-7.8 °Brix, mean 5.7). Ranges of this magnitude are comparable to those among Japanese and Chinese vegetable soybean genotypes evaluated in the south-eastern USA (Rao et al 2002) and in adaptation trials elsewhere (Zhang and Kyei-Boahen 2007; Guo et al 2020), confirming that introduction and systematic evaluation is a productive first step where adapted edamame cultivars are lacking.

Table 1. Descriptive statistics for pod, seed and biochemical traits of AVRDC vegetable soybean accessions at R6 stage (kharif 2018-19)

Trait	n	Mean	Min	Max	SD	CV (%)
Pods per plant	110	36.22	13.20	71.60	11.86	32.8
Seed moisture (%)	110	67.06	52.52	84.14	4.28	6.40
TSS (°Brix)	108	5.7	4	7.80	0.86	15.0
Pod length (cm)	111	5.08	2.90	7.30	0.76	14.90
Pod breadth (cm)	105	1.3	0.85	1.65	0.16	12.30
Pod thickness (cm)	112	0.94	0.57	1.30	0.13	14.40
100-pod weight (g)	112	286.55	100	516	82.09	28.60
Peel weight per pod (g)	111	6.35	1.70	14.80	2.33	36.70
100-peel weight (g)	111	126.9	34	296	46.61	36.70
Peel thickness (cm)	101	0.13	0.10	0.21	0.03	23.30
Seed length (cm)	110	1.46	0.90	2.10	0.19	12.70
Seed breadth (cm)	110	0.98	0.59	1.70	0.16	16.30
Seed thickness (cm)	110	0.71	0.41	1.05	0.11	14.80
Seeds per pod	67	2.42	2	3	0.35	14.60
100-seed weight (g)	110	59.69	18.1	141	19.35	32.4
Seed volume (cc)	110	1.06	0.22	3.03	0.42	39.10

Structure of variability: principal components and clusters

Four principal components with eigenvalues above unity together explained 73.3 per cent of total variation (Table 2, Fig. 1). PC1 (44.2%) carried high positive loadings for 100-pod weight (0.375), peel weight per pod (0.368), 100-peel weight (0.368), pod breadth (0.338), seed length (0.330), pod length (0.319), seed volume (0.296) and 100-seed weight (0.291) (Table 3), identifying pod-and-seed boldness as the dominant axis of divergence. PC2 (11.7%) was defined by pubescence density (0.554) and colour (0.484) against TSS (-0.395) and moisture (-0.376); PC3

(9.4%) by seeds per pod (0.716); and PC4 (8.1%) contrasted moisture and pubescence colour with pods per plant. The loading pattern has a direct breeding implication: boldness and sweetness load on orthogonal axes and therefore vary essentially independently in this material, so the two can be combined by selection. This is consistent with the finding of Kumar et al (2011) that sucrose and taste-related amino acids vary substantially among vegetable-type genotypes irrespective of seed size, and with multi-location analyses in which sweetness-related composition was governed more by genotype and environment than by seed dimensions (Yu et al 2021).

Table 2. Eigenvalues and variance explained by retained principal components (n = 52 accessions, 15 traits)

Component	Eigenvalue	Variance (%)	Cumulative (%)
PC1	6.75	44.20	43.90
PC2	1.78	11.70	55.50
PC3	1.40	9.40	64.70
PC4	1.24	8.10	73.30

Table 3. Loadings of the 15 quantitative traits on the first four principal components

Trait	PC1	PC2	PC3	PC4
Pods/plant	-0.06	0.29	-0.38	-0.42
Moisture (%)	0.05	-0.38	0.06	0.50
TSS (°Brix)	-0.05	-0.40	-0.34	-0.11
Pod length	0.32	-0.09	0.23	-0.21
Pod breadth	0.34	-0.09	-0.12	-0.15
100-pod wt	0.38	0.02	0.05	-0.09
Peel wt/pod	0.37	0.01	0.10	-0.17
100-peel wt	0.37	0.01	0.10	-0.17
Peel thickness	0.22	-0.14	0.15	0.28
Seed length	0.33	-0.13	-0.10	-0.06
Seeds/pod	-0.03	0.15	0.72	-0.13
100-seed wt	0.30	-0.03	-0.17	0.27
Seed volume	0.30	0.06	-0.26	0.15
Pubescence colour	0.08	0.48	-0.03	0.47
Pubescence density	0.17	0.55	-0.12	0.11

Fig. 1. Scree plot of variance explained by principal components

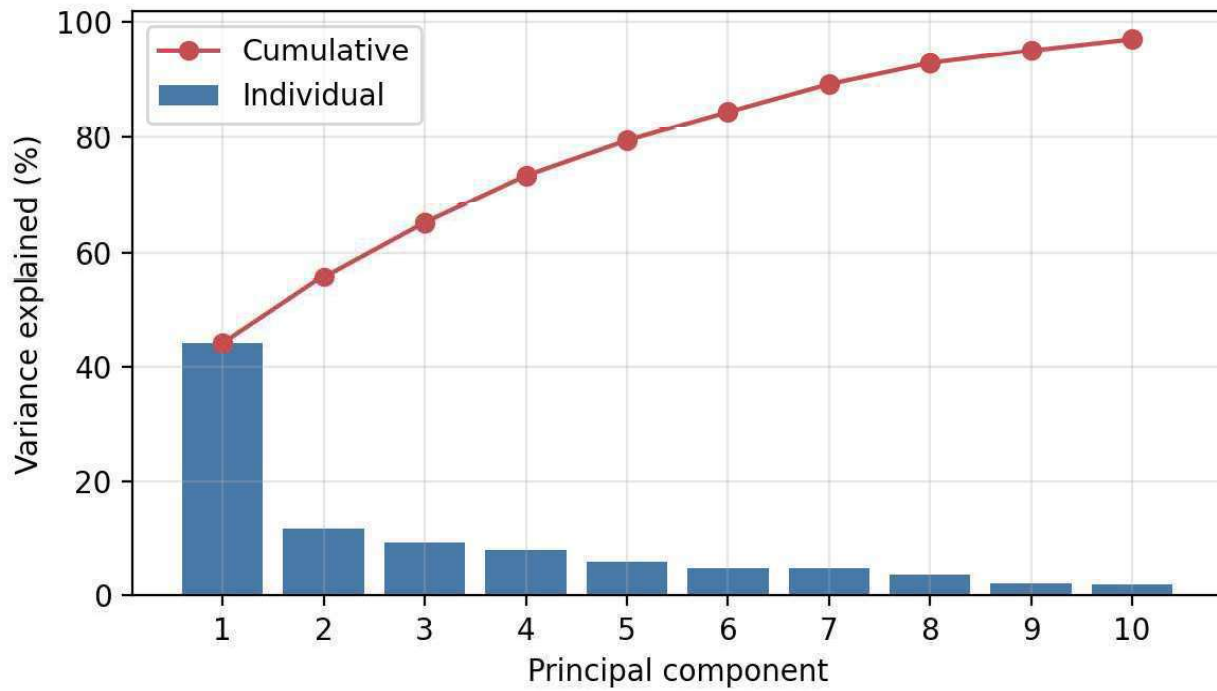
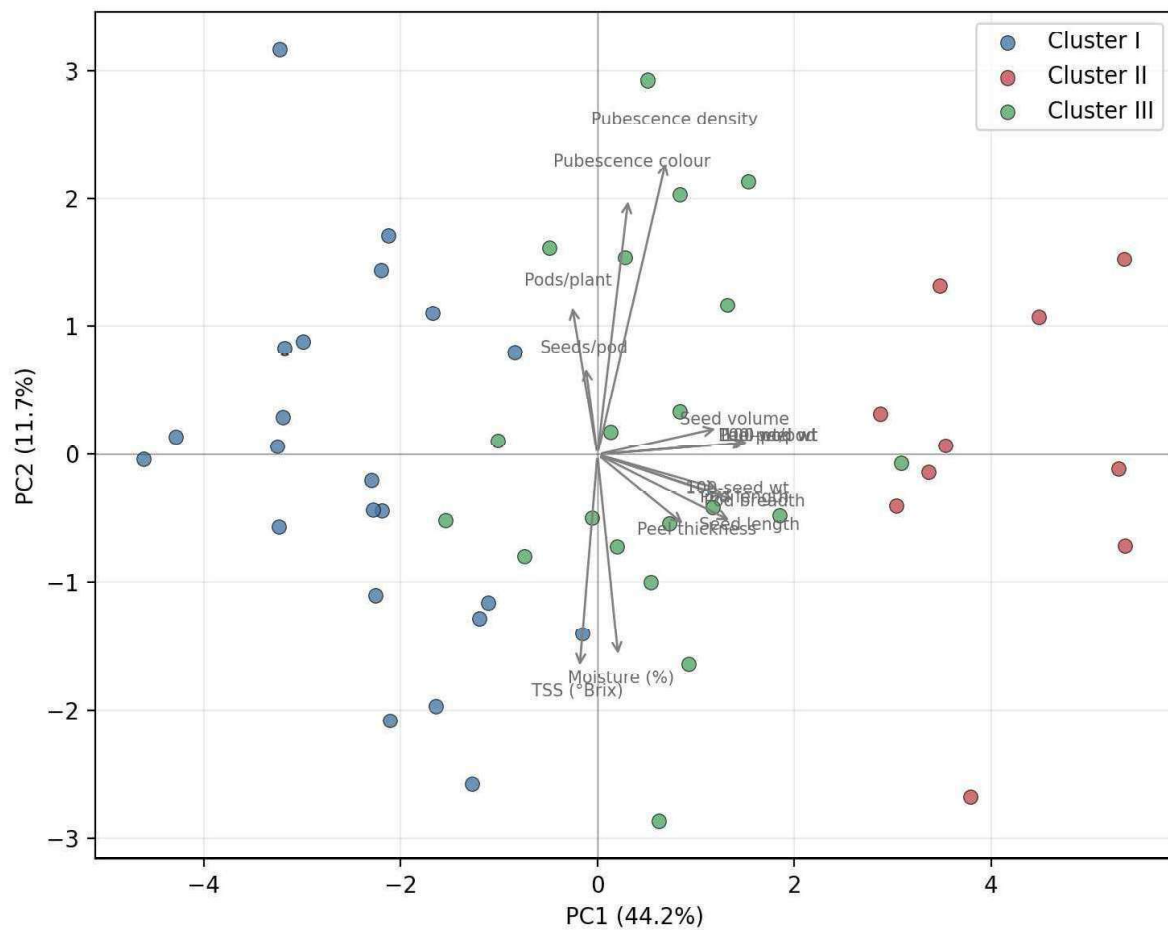


Fig. 2. PCA biplot (PC1 × PC2) of 52 accessions, coloured by Ward's cluster; arrows indicate trait loadings



Ward's clustering resolved three groups of 22, 10 and 20 accessions (Fig. 3, Table 4). Cluster I comprised small-podded, small-seeded lines (pod length 4.46 cm; 100-pod weight 217 g; 100-seed weight 42.8 g) that nevertheless recorded the highest pod number (42.3/plant) and highest mean TSS (6.2 °Brix). Cluster II combined the longest (6.24 cm) and heaviest pods (433 g/100 pods), the boldest seed (80.4 g/100 seeds), the thickest pod wall and densest pubescence, representing the bold vegetable-type ideotype.

Cluster III was intermediate throughout. Comparable group structure has been reported within vegetable soybean collections (Dong et al 2014). Hybridization between the sweet, prolific Cluster I and the bold Cluster II, followed by selection using the pod-based criteria derived below, offers a straightforward route to combining sweetness, pod number and boldness, the three attributes that jointly define commercial edamame quality (Masuda 1991; Konovsky et al 1994).

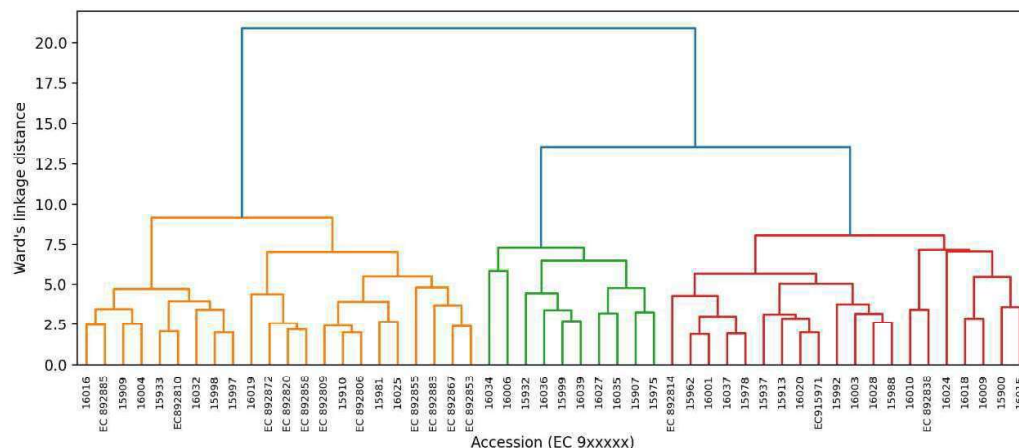
Table 4. Cluster means for the 15 quantitative traits (Ward's method, n = 52)

Trait	Cluster I (n=22)	Cluster II (n=10)	Cluster III (n=20)
Pods/plant	42.27	37.90	35.11
Moisture (%)	66.41	67.59	69.01
TSS (°Brix)	6.20	5.85	5.28
Pod length	4.46	6.24	5.24
Pod breadth	1.16	1.48	1.31
100-pod wt	217.23	433.03	299.50
Peel wt/pod	4.59	11.14	6.81
100-peel wt	91.86	222.80	136.10
Peel thickness	0.11	0.15	0.13
Seed length	1.29	1.71	1.51
Seeds/pod	2.40	2.43	2.49
100-seed wt	44.51	80.40	60.15
Seed volume	0.72	1.51	1.15
Pubescence colour	6	7.20	6.80
Pubescence density	5.36	7.40	6.60

Trait associations and derivation of non-destructive selection criteria

100-pod weight was strongly and positively correlated with pod length ($r = 0.78$, $p < 0.001$), pod breadth ($r = 0.85$, $p < 0.001$), 100-peel weight ($r = 0.94$, $p < 0.001$) and, most usefully, with 100-seed weight ($r = 0.73$, $p < 0.001$); 100-seed weight was also positively correlated with seed length ($r = 0.60$), seed volume ($r = 0.70$), pod breadth ($r = 0.68$) and pod length ($r = 0.50$) (all $p < 0.001$). The regression of 100-seed weight on 100-pod weight ($100\text{-seed weight} = 13.3 + 0.152 \times 100\text{-pod weight}$; $R^2 = 0.53$, $p < 0.001$) permits seed boldness to be estimated from a pod-level measurement taken without shelling. Evaluated as a binary classifier for bold seed (100-seed fresh weight ≥ 60 g) on the 52-accession set, the joint criterion 100-pod weight ≥ 300 g and pod length ≥ 5 cm achieved 83 per cent accuracy (sensitivity 0.75, specificity 0.88); relaxing to 100-pod weight ≥ 280 g raised sensitivity to 0.85 at 75 per cent specificity, appropriate when the breeder prefers to carry false positives forward rather than lose true bold lines. Pod-level proxies of this kind are especially valuable given that fresh pod weight is the major determinant of fresh yield in edamame (Rao et al 2002) and pod dimensional standards are already embedded in commercial grading (Konovsky et al 1994). Importantly, pods per plant was not significantly associated with 100-pod weight ($r = -0.16$, $p = 0.26$), indicating no strong built-in trade-off between pod boldness and pod number, while TSS was uncorrelated with 100-seed weight ($r = -0.06$) and moisture ($r = 0.16$), confirming that sweetness must be screened as an independent criterion rather than inferred from size.

Fig. 3. Dendrogram of 52 accessions based on Ward's clustering of 15 standardized traits



Sensory confirmation and its relationship with TSS

Among the 22 shortlisted lines (Table 5), softness averaged 3.80 (3.0–5.0), sweetness 3.15 (2.0–4.5), beaniness 2.95 (2.0–4.0) and overall taste 3.54 (2.1–5.0). Sweetness was negatively correlated with beaniness ($r = -0.57$, $p = 0.005$) and positively with overall taste ($r = 0.58$, $p = 0.005$), while beaniness depressed overall taste ($r = -0.52$, $p = 0.014$). These associations reproduce, on introduced bold-seeded material, the acceptability pattern observed in Indian germplasm (Pandey 2017) and in consumer studies abroad, where sweetness and mildness of off-flavour drove liking (Young et al 2000; Wszelaki et al 2005; Carneiro et al 2021a), and they justify placing beaniness alongside sweetness as an explicit rejection criterion in the scheme below. Notably, refractometric TSS was not significantly related to panel-perceived sweetness within the shortlist ($r = -0.27$, $p = 0.26$). This apparent paradox is well explained

by flavour chemistry: perceived sweetness in edamame is governed chiefly by sucrose and free amino acids such as alanine and glutamate (Masuda 1991; Tsou and Hong 1991; Kumar et al 2011), and multi-location compositional analysis has shown that calculated total sweetness based on measured sugars and alanine, rather than gross soluble solids, discriminates genotypes for sweetness (Yu et al 2021; Carneiro et al 2021b). TSS is therefore retained in the scheme as an inexpensive coarse filter, with the trained panel as the definitive quality gate; where facilities permit, sucrose-specific assay would strengthen the intermediate stage. Comparable descriptive-profile approaches have discriminated legume genotypes and even origins of the same variety in common bean (Sanz Calvo and Atienza del Rey 1999; Armelino et al 2006), supporting the reliability of small trained panels for this purpose (Stone and Sidel 1993; Carneiro et al 2020)

Table 5. Sensory scores (1–5 scale) and associated quality traits of 20 shortlisted lines against vegetable line Swarn Vasundhara

Accession	TSS (°Brix)	100-seed wt (g)	Softness	Sweetness	Beaniness	Taste
EC 916003	5	55.49	3.50	3	3.50	3
EC 916036	6	90.59	4	4.10	2.20	3.60
EC 916033	5.50	88.74	3.90	4	2.50	4
EC 915909	7	60	3.50	2	3.60	3.20
EC 915907	5.50	101.81	4.50	4.20	2.10	4.80
EC 916032	7.50	53.60	4.10	3.10	2.50	3.20
EC 915981	5	59.14	3.90	3.20	3.30	4
EC 916037	5	62.09	4.20	4.20	2.30	4.20
EC 915999	5.50	67.60	3.90	3	3.50	3.60
EC 916024	6	92.31	3	3.50	3	3
EC 915988	6	67.49	4	3	3.60	2.10
EC 915908	6.50	60.90	3	2.40	3.50	3.30
EC 916015	5.50	53.20	5	4.50	3	5
EC 916013	5	50.50	3.70	3	2.50	3.70
EC 915965	6.50	58.40	3.20	2.30	3.20	3
EC 916006	6.50	99.80	4.40	3.20	3	3.10
EC 916039	6	76.90	4.30	4.50	2.20	3.90
EC 915946	4.50	63.30	3.20	2.50	4	3.60
EC 915945	6	71.70	3.60	2	3.20	3.10
EC 915905	5.5	—	3.50	3	3.20	3
Swarn Vasundhara (check)	5	35.22	4.1	2.5	2.0	4.0

A sequential screening scheme for edamame selection

Integrating the above results yields a four-stage sequential scheme (Fig. 4) in which each stage is justified by a measured relationship and costs less than the stage it precedes. Stage 1 is the in-field visual screen on the whole nursery, applying the internationally accepted pod standards, pod length ≥ 5 cm, two to three seeds per pod, green pod colour and white/sparse pubescence (Shanmugasundaram et al 1991; Konovsky et al 1994); in the present material this passed 61 of 116 accessions. Stage 2 is the non-destructive pod-boldness screen, 100-pod fresh weight ≥ 300 g, which by the classification analysis above identifies bold-seeded lines (≥ 60 g/100 fresh seeds) with 83 per cent accuracy without shelling a single pod; 40 accessions passed. Stage 3 is the minimal-destruction quality screen, TSS ≥ 6 °Brix on macerated green seed of surviving lines, retained as a coarse sweetness filter because sweetness varies independently of size in this material; 15 accessions passed, and their mean 100-seed weight (74.8 g) confirms that the upstream pod-based stage

had effectively enriched for boldness. Stage 4 is the confirmatory trained-panel evaluation with explicit thresholds, sweetness ≥ 4.0 , beaniness ≤ 2.5 and overall taste ≥ 3.5 , values chosen from the observed distributions such that lines meeting them fall in the favourable tail for all three inter-correlated attributes. Five accessions, EC 916036, EC 916033, EC 915907, EC 916037 and EC 916039, cleared all four stages (Table 6 lists the fourteen stage-3 qualifiers with their characteristics). The scheme thus reduces the sensory workload from the full nursery to about one-eighth of it, which matters because panel evaluation is the costliest and least scalable step in edamame (Carneiro et al 2020). Analogous funnel logic, agronomic and pest screens preceding quality confirmation, has been used to shortlist edamame genotypes for commercial production in the mid-Atlantic USA (Lord et al 2021 as reviewed in Carneiro et al 2021b), and germplasm-level disease screens can be appended as a parallel stage where soilborne disease pressure limits establishment (Li et al 2024). For Indian conditions, the shortlisted lines should now enter replicated multi-location

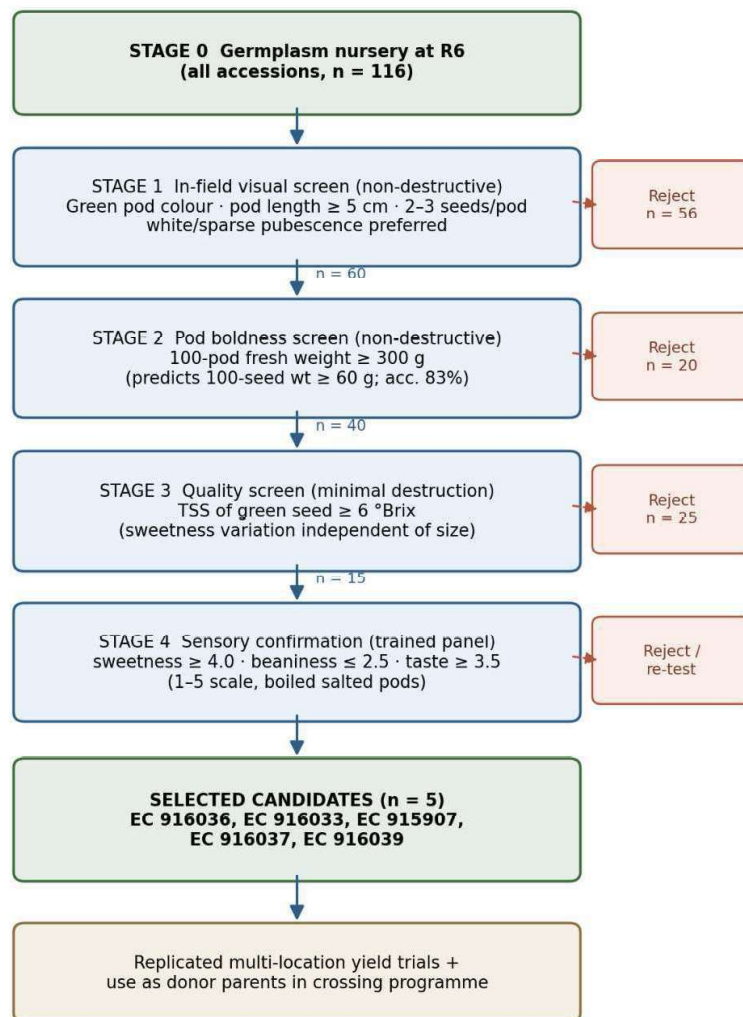
trials for fresh pod yield, the stage at which unreplicated nursery observations must be confirmed, and simultaneous use as donors of boldness and palatability in crosses with adapted Indian cultivars, in line with the complementation

strategy between Clusters I and II proposed above and with recent Indian edamame characterization efforts (Pardeshi et al 2024)

Table 6. Accessions qualifying the physical stages of the scheme (pod length ≥ 5 cm, 100-pod weight ≥ 300 g equivalent, TSS ≥ 6 °Brix; listed with benchmark 100-seed weight ≥ 60 g)

Accession	Pods/plant	Pod length (cm)	100-pod wt (g)	100-seed wt (g)	TSS (°Brix)	Pub. colour	Pub. density
EC 916028	34.80	5.97	380	80.78	6	w	ss
EC 916036	61	6.23	400	90.59	6	lb	n
EC 916034	31	6.20	363	94	6.50	br	d
EC 916027	31.80	6.27	516	73.25	6.50	w	n
EC 916024	18	5.67	250	92.31	6	w	d
EC 915988	29.80	5.23	413	67.49	6	lb	n
EC 915908	47.80	5.30	293	60.90	6.50	w	ss
EC 916006	47.20	5.03	376.67	99.80	6.50	lb	s
EC 916039	51	5.93	433.33	76.90	6	lb	ss
EC 915979	23.80	5.33	306.67	76.10	6	lb	d
EC 915945	13.20	5.73	383.33	71.70	6	br	n
EC 916040	36.20	5.73	350	72.50	6	lb	n
EC 916030	0	5.73	376.67	88.50	7	w	d
EC 915921	60	5.37	300	67.90	6.50	br	n

Fig. 4. Sequential screening scheme for selection of vegetable-type (edamame) soybean derived from the present study; n values show accessions passing each stage



Conclusion

Characterization of bold-seeded AVRDC vegetable soybean introductions under central Indian conditions revealed wide exploitable variability, with pod-and-seed boldness as the principal axis of divergence and sweetness varying independently of size. These relationships were converted into a validated, stage-wise selection scheme, visual pod standards, a non-destructive pod-boldness criterion (100-pod weight ≥ 300 g with pod length ≥ 5 cm; 83% classification accuracy for bold seed), a TSS filter and a confirmatory sensory panel, that narrowed 120 accessions to five candidates while reducing sensory workload roughly eightfold. The scheme provides breeders a repeatable decision pathway for edamame selection, and the identified accessions merit replicated multi-location evaluation and immediate use as parents in Indian edamame variety development.

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