Potential of science and technology to enhance pulses productivity through intensified cropping systems in Africa and Latin America

B. B. Singh, Texas A&M University



Outline of presentation

1. Grain legumes vs dry pulses
2. World production of dry pulses
3. Current production constraints
4. Scientific and technical interventions to enhance productivity and intensify cropping systems

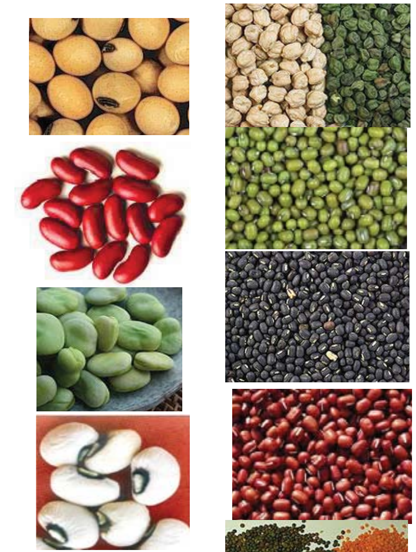
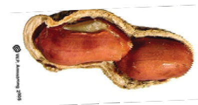
- Increase yield/ha in time and space
  - reduce yield gap and yield losses
  - breed for higher yield potential
  - intensify cropping systems
- Maximise fertilizer and water use efficiency
  - breed for tolerance to heat, drought, low -P
- Increase consumption and marketing
  - breed for high protein and health factors
  - develop diverse food products

-Increase the cultivated land area

6. Future prospects and research needs

1. Major Grain Legumes

Common name	Regions of diversity
Peanut	South America
Pigeon pea	India
Chickpea	SW Asia, Ethiopia, India
Soybean	East Asia
Lentil	SW Asia, Mediterranean
Common bean	Mexico, Guatemala
Pea	SW Asia, Mediterranean
Faba bean	Asia, Mediterranean
Adzuki bean	Japan, China
Mung bean	India, SE Asia
Cowpea	Africa, India


1. Major Grain Legumes

Co-evolution of grain legumes with cereals

Marvels of nature:

The starchy foods like cereals and tuber crops co-evolved with protein rich grain legumes and minerals which complement to make a balanced diet for humans.

1. pigeon pea and mung bean with rice and millets in India
2. Soybean with rice in China;
3. peas, lentils and chickpeas with wheat and barley in the Fertile Crescent;
4. cowpea with sorghum in Africa.
5. beans with maize in Central America and
6. peanut with potato and cassava in South America

1. Major Grain Legumes

Nutritional composition of major cereals and legumes

CEREAL	PROTEIN	FAT	ASH	FIBRE	CARBOHYDRATE
Rice	7.3	2.2	1.4	0.8	64.3
Sorghum	8.3	3.9	2.6	4.1	62.9
Maize	9.8	4.9	1.4	2.0	63.6
Wheat	10.6	1.9	1.4	1.0	69.7
Pearl Millet	11.5	4.7	1.5	1.5	63.4
Peas	24	1.2	3.5	3.8	60.0
Beans	22	1.5	3.0	4.0	64.0
Cowpea	24	1.5	3.5	5.6	62.0
Chick pea	21	3.4	3.0	4.0	63.0
Pigeon pea	20	1.0	4.1	2.3	70.0
Peanut	24	45	2.3	2.8	23.0
Soybean	41	20	3.1	5.0	40.0

Essential amino acids: Iso-leucine, Leucine, Lysine, Methionine, phenylalanine Threonine, Tryptophane, Valine.

* Cereals are deficient in Lysine and tryptophane; * Legumes are deficient in Methionine

1. Grain legumes vs Pulses

Grain legumes : All crops of family Leguminosae (Fabaceae)

Pulses : grain legumes grown solely for dry grains for food such as beans, peas, cowpea, chick pea, lentil, pigeon pea, adzuki bean, mung bean, urd bean and Faba bean.

This excludes green beans, green peas and yard long beans which are vegetable crops; soybean and peanut which are oil seed crops and clover and alfalfa which are fodder crops.

Importance of Pulses:

1. poor man's meat
2. rich man's health food.
3. nutritious haulms for livestock
4. field residues for enhanced soil fertility

1. Major Dry Pulses – Seed types

2. Production of dry pulses (million tons) in different regions, 2010

Region	Bean	ChicKP	CowP	Lentil	Pea	PigenP
East Africa	2.87	0.41	0.33	0.13	0.39	0.44
Southern Africa	0.06	0.00	0.005	0.00	0.00	0.00
West Africa	0.29	0.00	4.65	0.00	0.01	0.00
North America	1.70	0.22	0.066	2.34	3.51	0.00
Central America	1.65	0.13	0.00	0.00	0.00	0.00
Caribbean	0.18	0.00	0.03	0.00	0.00	0.03
South America	3.97	0.01	0.64	0.01	0.18	0.00
Asia	11.24	9.39	0.90	1.93	1.93	3.21
Europe	0.43	0.08	0.03	0.45	3.81	0.00
Oceania	0.04	0.60	0.00	0.14	0.32	0.00
World	23.23	10.94	6.57	4.64	10.2	3.68

3. Current Production Constraints

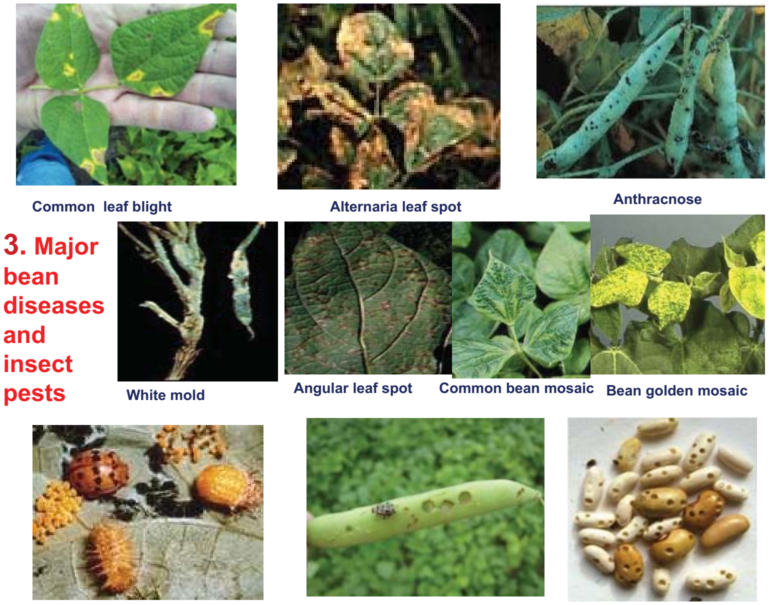
* **Major diseases**
  - **Bean -** anthracnose, rust, angular leaf spot, common bacterial blight, Bean Golden Mosaic Virus and Bean Common Mosaic Virus
  - **Cowpea -** Bacterial blight, cowpea aphid borne mosaic, blackeye cowpea mosaic, severe mosaic etc.

• **Major insects**
  - **Bean –** Leafhopper, white fly, bean pod weevil, Mexican bean beetle and bean seed weevils
  - **Cowpea -** Aphid, thrips, Maruca pod borer, pod bugs, curculio and seed weevils

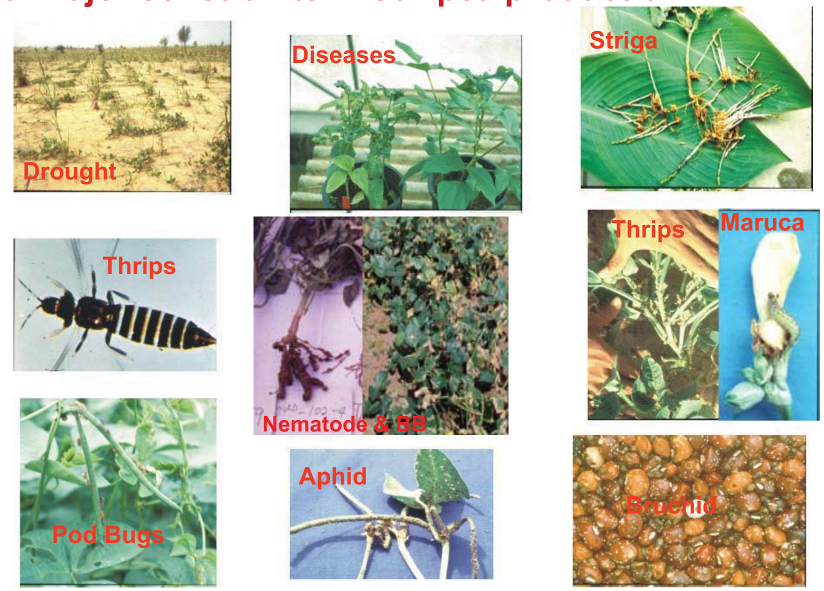
* **Weeds and parasitic plants**
  - Bean and cowpea – major weeds of the region
  - Cowpea – parasitic plants – Striga and Alectra (Africa only)

* **Abiotic constraints**
  - Bean and cowpea – Heat, drought, low soil fertility, low-P and Aluminum toxicity, shading under intercropping

3. Major bean diseases and insect pests



3. Major constraints in cowpea production



3. Abiotic constraint - Low fertility including especially Low-P

4. Scientific and technical interventions to increase pulses production

The challenge is how to increase pulses production with little or no extra land and limited inputs without diminishing the natural resource base.

General strategy:

- bridge the current yield gap – crop management
- increase the yield potential – breeding and biotech
- reduce the yield losses – IPM, breeding & biotech
- intensify cropping systems - diverse varieties & agronomy
- maximise fertilizer and water use efficiency
- increase the cultivated land area – possible in Africa and South America
- increase consumption and marketing

4.1.Bridging the yield gap- crop management

Cowpea production (x 10^3 t) and average yield

Country	1961	1981	2010	kg/ha (2010/1961)
Burkina Faso	74	130	432	558/400
Mali	20	18	110	433/200
Myanmar	10	8	170	1352/539
Niger	50	275	1,800	320/117
Nigeria	431	560	2,916	890/354
Senegal	12	26	86	381/250
USA	33	12	49	1,488/651
Brazil	250	267	611	478/262
World	880	1,300	6,600	527/361

The yield gaps between and within the countries over time are mainly due to low inputs and poor crop husbandry.

The difference between experimental yields (1000 to 2000 kg/ha) and farmers yields are much greater.

4.1.Bridging the yield gap- crop management

Bean production (x 10^3 t) and average yield

Country	1961	1981	2010	kg/ha (2010/1961)
Argentina	33	224	338	1261/1060
Brazil	1744	2340	3202	925/676
Burundi	230	294	201	1095/1151
China	2150	1751	1540	1690/687
Guatemala	41	81	182	814/643
Honduras	42	42	68	612/496
Haiti	37	50	62	633/421
India	1686	2944	4870	451/258
Kenya	55	250	390	567/478
Mexico	723	1331	1156	709/476
Nicaragua	39	59	138	765/639
Rwanda	86	192	327	1025/660
Tanzania	80	250	950	748/414
USA	895	1485	1442	1864/1541
World	11,228	15,278	23,229	777/493

The yield gaps between and within the countries over time are mainly due to low inputs and poor crop husbandry.

The difference between experimental yields (1000 to 2000 kg/ha) and farmers yields are much greater.

Maize

4.1.Bridging the yield gap

- need for optimum fertility

Plant biomass consists of -

1. In cereals -

CO_2 - 90% + H - 5% (from water) + NPK and other elements – 5%

Thus 95% from air and 5% from soil!

2. In legumes-

CO_2 - 90% + H - 5% (from water) + N – 3% (from air) + PK and other elements – 2% (from soil)

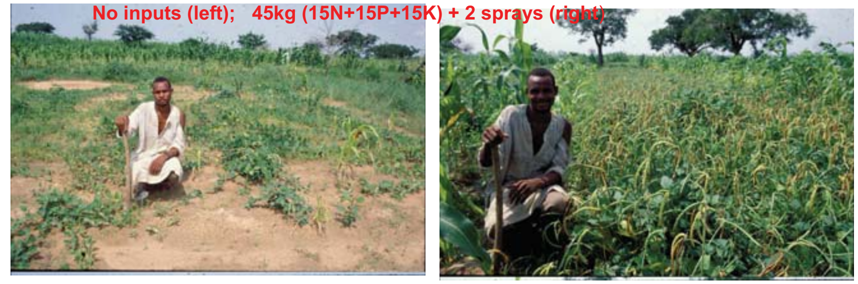
Thus 98% from air and 2% from soil!

This means that if we invest 5% in terms of inputs to cereals, we get 95 % biomass free! And if we invest 2% in terms of inputs, we get 98% biomass free!

Bean & cowpea

4.1. Effect of fertilizer weed and insect management on yield

No inputs (left); 45kg (15N+15P+15K) + 2 sprays (right)



4.2.Breeding for higher yield potential

Improved plant type and greater harvest index in cowpea

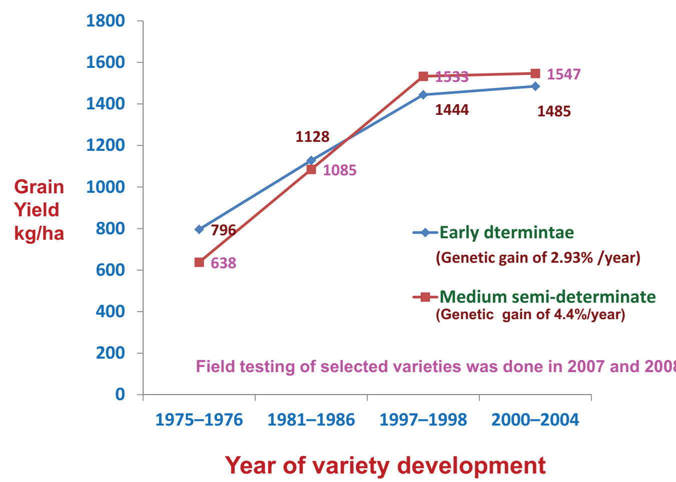
4.2. Improved grain type and dual purpose cowpea varieties

Performance of (kg/ha) improved dual purpose cowpea varieties

Cultivar	Grain	Fod.	Mat.
IT97K-568-19	2582	5998	85
IT90K-277-2	2544	3415	80
IT97K-568-18	2510	2166	75
IT98K-205-9	2143	2332	75
IT95K-627-34	2143	2083	79
IT86D-719	1788	1208	70
Dan Ila	1753	2249	85
Bambara nut	334	1000	100
Groundnut	421	5165	100
SED	312	420	2

4.2. Progress in breeding for higher yield potential in cowpea at IITA

(Kamara et al 2011 . Crop Science 51:1877-1886)

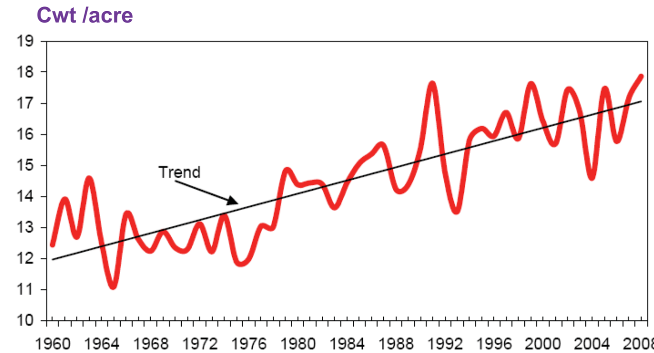




4.2. Breeding for Improved plant types in beans


Bush determinate (left), Erect determinate (middle), Viny indeterminate (right)

4.2. Progress in average yield of dry beans in USA over time



Cwt = 100 pounds
Source: USDA, National Agricultural Statistics Service, Crop Production

4.3. Reduce the yield losses – Conventional and biotech approaches to breed for resistance to biotic and abiotic stresses

Conventional breeding:

Cowpea – resistance to major diseases, Striga, Alectra, aphid, bruchid, and tolerance to drought, heat, photo-insensitivity and low-P

Beans – resistance to major diseases, Mexican bean beetle, bruchid and tolerance to drought and low-P.

Biotechnology – genetic engineering:

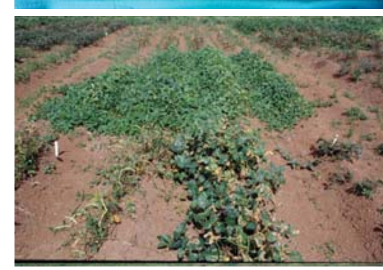
Cowpea – Bt-gene for resistance to Maruca pod borer, Alpha Amylase Inhibitor and egg cystatin for resistance to bruchids, RNAi strategy for resistance to both CPSMV and CABMV. Acetohydroxyacid synthase (AHAS) for tolerance to imidazolinone.

Beans - RNAi strategy for resistance bean golden mosaic virus, DREB1A gene (drought tolerance) and an oxalate decarbolixase gene (oxdc) for tolerance to white mold (Sclerotinia).

(Courtesy T.J. Higgins in Australia and F. Aragao in Brazil)

4.3. Resistance to major diseases in cowpea





4.3. Resistance to Striga and Alectra in cowpea

4.3. Resistance to aphid, thrips, bruchid and Maruca in cowpea

4.3. Combined resistance to major pests in cowpea

Progress in pyramiding genes for resistance in cowpea*

Pest/disease	Ife Brown (1973	TVX 3236 (1978)	IT82D-716 (1982)	IT84S-2246 (1984)	IT90K-59 (1990)	IT97K-499-35 (1997)	IT00K-1251 (2000)
Anthracnose	S	R	R	R	R	R	R
Cercospora	S	R	R	MR	R	R	R
Brown Blotch	S	R	R	MR	R	R	R
Bacterial pustule	S	R	R	R	R	R	R
Bacterial blight	MR	MR	MR	MR	MR	R	R
Septoria	S	S	S	S	S	R	R
Scab	S	M R	MR	MR	MR	R	R
Web blight	S	MR	MR	MR	MR	R	R
Yellow mocaic	S	S	R	R	R	R	R
Aphid-borne mosaic	S	S	R	R	R	R	R
Golden mosaic	R	R	R	R	R	R	R
Aphid	S	S	S	R	R	R	R
Thrips	S	MR	MR	MR	MR	R	R
Buchid	S	S	R	R	R	R	R
Striga	S	S	S	S	R	R	R
Alectra	S	S	S	S	R	R	R
Nematode	S	S	S	R	R	R	R

+ The earlier variety is one parent of the next variety. See dates in parenthesis after each variety
R = resistant; MR = moderately resistant; S = susceptible.

Performance (kg/ha) of most promising cowpea varieties at Minjibir

	2 sprays		No spray	
Variety	Grain	Fodder	Grain	Fodder
IT90K-277-2	2697	2219	549	3236
IT95K-321-1	2235	2619	312	3043
IT95K-193-12	2020	1513	496	1462
Dan Ila (local)	1407	3050	14	3677
SED	381	630	86	951

4.3. Yield loss in cowpea due to insects

4.3. Genetic transformation of cowpeas with Bt-gene

Bt- Cowpea for Maruca resistance

Cowpea has been recently transformed with Bt-Cry1Ab and being tested for resistance to Maruca pod borer

Toxicity of Bt-proteins to *Maruca larvae*

Bt protein	LD 50	LD 90
Cry 1Aa	1.00	2.20
Cry 1Ab	0.03	0.09
Cry 1Ac	0.43	5.60
Cry 2A	0.09	0.56

Thanks to

T.J. Higgins
supported by
CSIRO , AATF, RF, Monsanto, IITA, NGICA, Nigeria and other NARS





4.3. Breeding for resistance to diseases in Beans

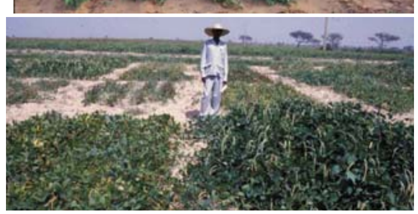



4.3. Breeding for tolerance to drought, heat and high BNF





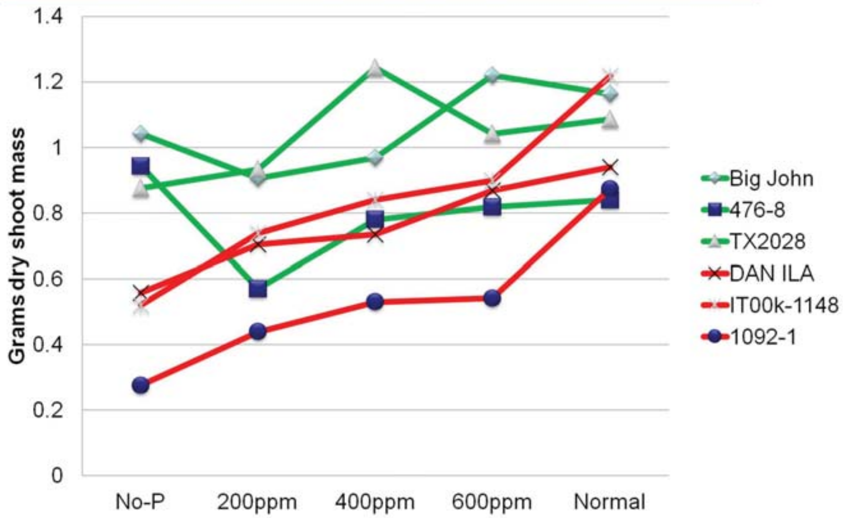





4.3.Breeding for low-P tolerance




4.3. Breeding for tolerance to Low-P



5. Sustainable intensification of cropping systems

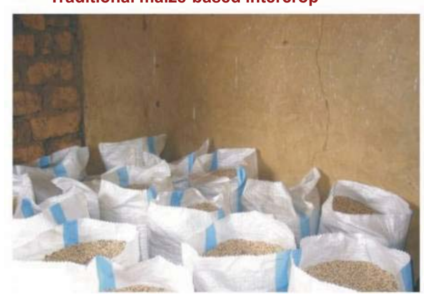

Traditional 'sorghum-cowpea' intercropping

Improved 'sorghum-cowpea' strip cropping

5. Improved cowpea –cereals strip cropping in Africa


Traditional maize-based intercrop


Improved 2 rows maize : 4 rows double cowpea


The harvested produce from first cowpea –1.5t/ha


The second cowpea and harvested maize in the field – up to 500% more production.

5. Double strip cropping of cowpea with maize

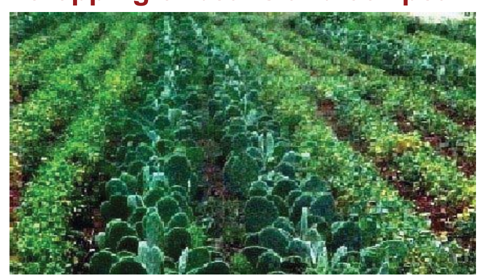
5. New land under cowpea in Brazil

New clearings in 2009 , Belem, PARA State

5. Soybean-cowpea double cropping in Brazil

5. Combining cowpea and bulk storage in Brazil

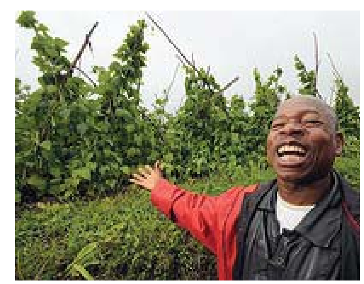
5. Other examples of intensive cropping of beans and cowpea



Beans intercropped with prickly pear cactus in Mexico

Cassava – cowpea in Nigeria

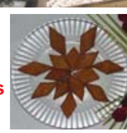
Wheat (Nov.-March) – cowpea (April-June) – Paddy (July-October)

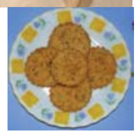


Climbing beans in Rwanda

6. Breeding for traits associated with food quality

1. Physical properties of seed
   - i). Seed coat color – antioxidants, antibacterial and antifungal activities
   - ii). Seed size, volume and density – swelling and cooking properties
   - iii). Seed coat thickness – fiber content and boiling properties
   - iv). Seed texture – seed coat contents and food preparation
2. Chemical and nutritional properties
   - i). Protein
   - ii). Fat
   - iii). Carbohydrate
   - iv). Minerals
   - v). Vitamins
3. Health factors
   - i). Antioxidants
   - ii). Beneficial phytochemicals
4. Cooking properties and taste
   - i). Cooking time
   - ii). Functional properties of flour and foods
   - iii). Taste and acceptability
5. Development of diverse food products
   - i) foods/snacks for home and markets
   - ii). Cereals plus pulses mixed extruded foods





6. Breeding for improved nutritional composition and fast cooking time in cowpea

Genetic variability in dry seeds:

- 22.9 to 32.5% for protein,
- 2.9 to 3.9% for ash,
- 1.4 to 2.7% for fat,
- 59.7 to 71.6% for carbohydrate – mostly complex,
- and 21.1 to 61.9 minutes for 50% cooking time.
- 236 to 1083 total antioxidants
- Glycemic index <40 (glucose is 100)
- 45 to 80 ppm iron, 25 to 46 ppm zinc, 600 to1300 ppm Ca

6. Genetic variability for fiber content in cowpea

Smooth coat

Seed coat %

10.5

11.5

13.5

Rough coat

Seed coat %

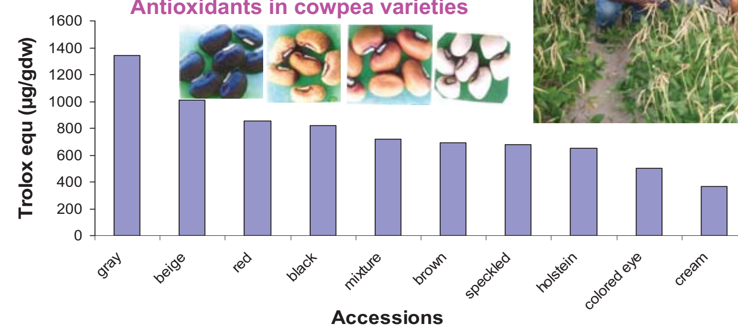
6.8

6.5

5.7

6. Breeding for nutrition and health factors

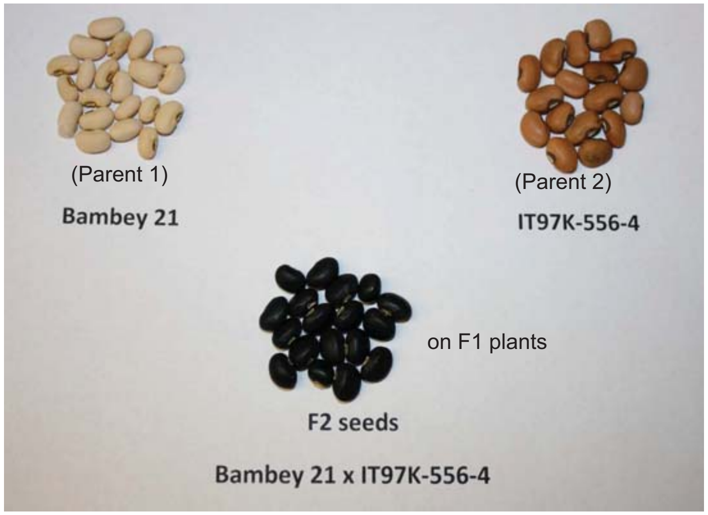
Antioxidants in cowpea varieties



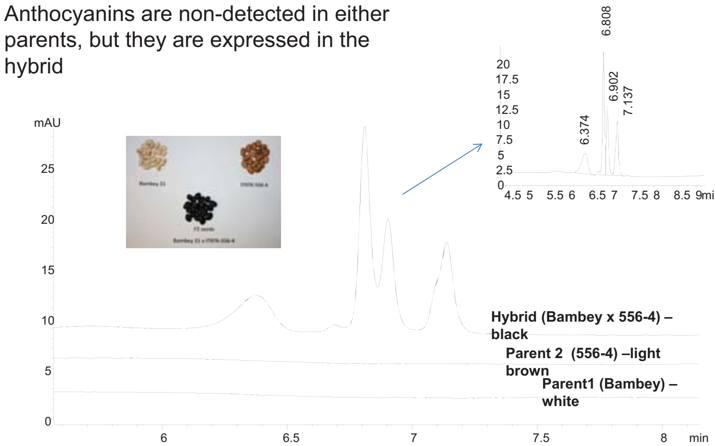
Protein and minerals in improved cowpea varieties

Variety	CP	Fe	Zn	Ca	K	Mg	P	S
IT97K-1042-3	30	69	45	858	14378	1987	5139	2361
IT98K-205-8	27	60	42	994	13672	1952	4922	2109

6. Breeding for nutrition and health



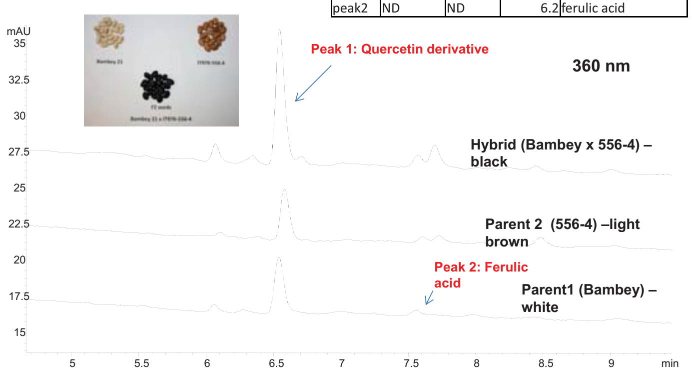
Gene complementation phenomenon
Anthocyanins are non-detected in either parents, but they are expressed in the hybrid



3-D overlay of signals at 520 nm of parents and hybrid

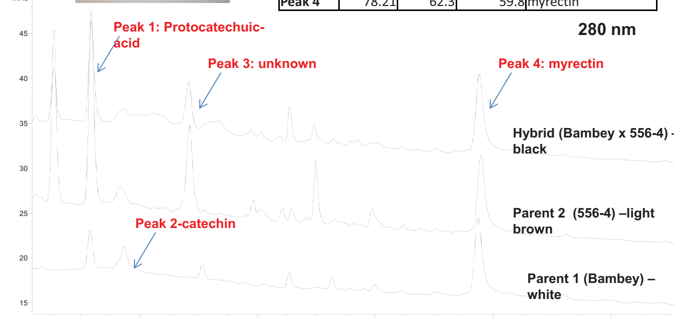
Hybrid vigor in Quercetin derivative

	Area			
360 nm	P1	P2	hybrid	possible compounds
peak1	19.29	12.26	32.96	Quercetin derivative
peak2	ND	ND	6.2	ferulic acid



3-D overlay of signals at 360 nm of parents and hybrid

	Area			
280 nm	P1	P2	hybrid	possible compounds
peak 1	24.4	105	53.66	protocatechuic acid
peak 2	23.61	22.05	ND	catechin
peak 3	8.45	58.16	25.28	unknown
Peak 4	78.21	62.3	59.8	myrectin



3-D overlay of signals at 280 nm of parents and hybrid

6.Create awareness that dry pulses are good for health and heart.

These are packed with high protein and rich in calcium, iron, zinc, fibers complex carbohydrates, and antioxidants which reduce risk of heart diseases and cancer

Eat less meat and more pulses for good health and active life

6. Create awareness that eating too much meat causes health problems for rich and food grain shortage for the poor

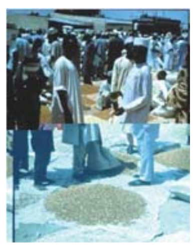
Even the rich should consume less meat and more food legumes

7. Increase local and international trade for dry pulses

While assisting increased local production in the countries of project focus:

- Encourage countries like USA, Canada, Australia and Brazil with more land and excess food grains to produce more food legumes for export to Asia and Africa where about 1.5 billion people would be added by 2050 and who mostly depend upon food legumes for dietary protein.

India is currently importing over 3 million tons of pulses and Nigeria imports over 500,000 tons of cowpea each year. This would be much more in the next 30-40 years.



8. Future prospects and research needs

1. Demand for food legumes would increase in the coming decades.
2. The production of many food legumes has remained stagnant.
3. Because good lands have gone to wheat, rice and maize
4. Food legumes have been pushed to marginal lands
5. Chickpea, lentils, pigeon pea, field pea and beans mature in 90 -120 days or more and compete with cereals for land.

How to increase food legumes production in this century?

* The only answer is to develop and cultivate short duration legumes in existing niches in cereal-based systems
* Some '60-day' cowpea varieties are already being adopted in India as a niche crop in wheat-rice system and as a double crop in maize-based system in Nigeria
* There has been a major increase in cowpea production in the last 10 years compared to other pulses

World production of food legumes ($x10^6$ tons)

Crop	1961	1981	2001	2010	% +61	% +01
Beans	11.2	15.3	18.2	23.2	107	27
Chick pea	7.7	5.8	6.9	10.9	41	57
Cowpea	0.87	1.3	3.7	6.6	658	78
Lentils	0.85	1.4	3.3	4.6	441	27
Pea	7.3	7.7	10.3	10.3	41	0.0
Pignpea	2.2	2.1	2.9	3.6	64	24
Pulses ttl	40.8	41.6	55.8	67.7	66	21
Cereals ttl	876	1632	2108	2209	152	5
Pulses/capita	13 kg	9 kg	9 kg	10 kg		
Cereals/cap	284 kg	360 kg	342 kg	329 kg