TRABAJOS DE INVESTIGACION

PRODUCTION AND NUTRITIVE VALUE OF SOYBEANS[1]

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SUMMARY

Soybean world production has been increasing at a rate of 5.2% per year (average yield is around 1,400 kg/ha). This production has been solely used for oil extraction and the protein meal obtained for animal rations, but lately it is being used for human consumption. Brazil, the third largest producer, has had a yearly rate of production increase of 32% in the last years. Average yields in Brazil are still low (around 1,500 kg/ha), but in experimental results, yields over 3,000 kg/ha have been obtained. Some problems need still to be solved, such as obtention of adapted varieties, soil fertility, adequate agronomic practices, damage by insects and diseases. Protein and oil contents are highly negative correlated, they are genetically controlled and can also be influenced by environmental conditions and agronomic practices. To breed for high protein (above 48%) enhances a decrease in oil and yield, but new varieties containing 43% protein and with a good yielding capacity have been developed lately. Methionine content

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varies from 1.0 to 1.6% g/16g N; there is a correlation of 0.56 to 0.58 between methionine in the protein and protein in the seed. Particular attention has been given to toxic factors such as trypsin inhibitors, whose action is related to the availability or utilization of methionine; this effect, however, can be eliminated by heat.

PRODUCTION

The Second World War brought along a great demand for oil and protein in the international market with the consequent expansion of soybean production which reached an important position among crops all over the world.

This legume has been known to man for more than 5,000 years and, according to Vavilov (1), is native of China. There, as well as in other Oriental contries, it has been used for human consumption under several ways of preparation.

Soybeans were brought to America around the XIX century, at which time it was utilized for hay production. Nowadays it is the prime world source of edible oil, and its meal has become an important protein constituent in animal rations. Recently, there has been a tendency for a direct use of its protein in human consumption.

It is a tropical crop with a great yield potentiality and also a good source of protein and oil; its utilization can be very helpful in solving the malnutrition problems in the tropics. Approximately two-thirds of the world population live in this Region which faces the problem of a rapid demographic increase and probably worse than this, where human diets are most deficient.

The world production of soybeans has shown a continuous expansion at a rate of 5.2% per year during the period 1965-72. During the crop year 1971-72 it reached 47,750,000 tons, which was 9.6% higher than that of the previous year. World production in 1974-75 is estimated at 67,500,000 tons (2).

During the years 1973-74 the United States of America contributed with 67% of the total world production, followed by the Republic of China and Brazil, with 15% and 11%, respectively. These three countries are responsible for almost 93% of the total world production. The United States has been the world production leader since 1954.

Soybean exportations have also been increasing; during the period 1968-72 there was an increase of 65% in the international transactions. Again, the United States appears as the leader of this market, supplying in 1973, 87.2% of the total demand (13,240,000 tons), with Brazil as the second larger exporter, with 12% (1,830,000 tons).

Brazilian Soybeans Production

Soybeans where introduced in Brazil at the end of the XIX century, and in the last ten years its production has shown substantial increases (approximately 32% per year); in 1973-74 it reached 7,112,000 tons (2).

All Brazilian production is located between the latitudes 15° to 33°S, but new areas are being developed, mainly above the Tropic of Capricorn where a "Cerrado" area is located. This type of land is suitable for soybeans production, but its use is limited by problems related to physical and chemical properties of the soil.

In Rio Grande do Sul, the first producer State, soybeans are planted after wheat; minimum tillage practices are frequently used.

In the State of São Paulo, the third producer, soybeans have shown a production expansion of 54% per year during the period 1964-65 to 1971-72; in 1974 it produced 642,000 tons which was 95% higher than the production obtained in 1973.

Besides the high prices obtained by this crop in the international market, one of the reasons for the rapid expansion in São Paulo, mainly in the region of "Alta Moggiana", which is considered the Soybean Belt of this State, was the substitution of the traditional variety "Pelikan".

This variety was brought from Louisiana, and was planted as the only variety because of its rusticity; however, it has disadvantages such as low-yielding capacity, undeterminate type of growth, and susceptibility to "bacterial pustule". New varieties were therefore introduced from Florida, most of them belonging to maturity group VIII, with a determinate type of growth, a good yielding capacity, and also, capable of replacing the "Pelikan" variety with great advantages. As a consequence, aside from the problem of obtaining varieties adapted to our environmental conditions, we have to determine the production practices for this new type of varieties (3,4).

Our experimental results have shown yields of over 3,000 kg/ha, but the commercial yields are not very close to this. There are many problems to be solved such as adequate plant nutrition; pH problems and, related to this, aluminum toxicity; use of efficient strains of *Rhizobium japonicum* (5) and because of this, responses to nitrogen application have been obtained (6); attack of insects and diseases and seed quality, which decreases with late rains that occur during the maturity stage, leading to proliferation of pathogens, and in some cases to seed germination inside the pod (7).

Brazil is reaching a point where processing and industrialization is a crucial need. In 1973, Brazil exported 1,789,000 tons of beans, 1,581,000 tons of soybean meal, and 20,500 tons of refined oil (8).

Practically all the Brazilian soybean production is used for oil extraction and exports. A small part of the meal is used for animal feeding. Human consumption of this legume or even its products is almost nil, in spite of several Brazilian studies done on the subject since 1958 (9). Soybeans are a good source of foreign exchange to Brazil, but they have not contributed to solve local malnutrition problems.

COMPOSITION OF THE SEED

In general, protein and oil account for 60% of the dry weight of the seed, and its content of carbohydrates is almost 34% (10). Carbohydrates have received particular attention, mainly not as a source of calories but as related to the problem of flatulence. Stachyose and raffinose have been found to be related with the production of gases (11). Processing, however, can eliminate these oligosaccharides.

Another particular component is the fiber content (around 50.0%) which is present in its totality in the hulls. Some recent evidences have shown that a certain amount of fiber is necessary to maintain a proper flow of material through the intestines.

As in other legume crops, soybean protein is deficient in the sulfur-containing amino acids, methionine and cystine but presents a reasonable lysine content which makes it suitable for use in mixtures with cereals. In general, processing decreases protein quality, and the addition of methionine enhances its protein efficiency ratio (PER).

Soybean oil is rich in unsaturated fatty acids, with a content of around 85% (12). The main unsaturated fatty acids present are oleic, linoleic and linolenic; some evidence suggests that the linolenic acid content is related to oil quality. Iodine number, an indication of the amount of unsaturated fatty acids, is around 120 to 141, with an average of 130. Liberation of free fatty acids elicits off-flavors.

In relation to commercially grown varieties, wild soybeans present a higher protein content, lower oil content, and a higher iodine number as a consequence of its high lionolenic acid content.

Variability in the Protein and Oil Contents

Oil and protein contents can be influenced by the genotype of the variety and also by the planting location as a consequence of soil and environmental conditions. A negative correlation of -0.26 to -0.74 was found between oil and protein (13).

Oil content has been the main purpose of breeding in order to suit industrial purposes. Nutritionally, protein is the most valuable part of the seed and breeding for high-protein varieties has been done in the last years. One question remains however. How will industry react to this high-protein varieties in relation to those used commercially?

Piper and Morse (14), determined the oil and protein contents in 500 samples and found that protein ranged from 30 to 46% and oil from 12 to 24%. In the same way, Dies (15), screening 128 varieties found protein contents varying from 32.4 to 50.2%, with an oil content of 13.9 to 23.2%. In general, commercially-grown varieties in the United States yield 39 to 41% of protein and from 20.5 to 21.5% of oil calculated on a dry basis (16).

High-protein varieties present a low productivity. Johnson, Robinson and Comstock (17) found phenotypic correlations of -0.08 to -0.33 between these two traits, and Byth, Weber and Caldwell (18), found a coefficient of -0.14.

Protein contents of around 46 to 48% have been found in several soybean lines, but they present low oil content and yield (19). High-protein varieties such as "Sioux", produced 52% of protein and 15% of oil when planted in Minnesota, while "Biloxi", when planted in Gainesville, produced 48% protein and 20% oil (16).

Some varieties with high-protein content and good yielding capacity belonging to Group II of maturity were lately released; "Protana" yielded 45º/o protein, with a seed yield slightly higher than the most common varieties planted in Indiana (20); "Provar" produces 4º/o more protein and 1º/o less oil and its yield is 5º/o less than "Amsoy" and "Corsoy" (21).

In São Paulo we have found protein contents ranging from 31.8 to 38.0º/o, and an oil content varying from 17.2 to 25.9º/o on a dry matter basis (22). Maybe our conditions are more favorable for increased oil content.

Collins and Carter (23), reported that oil and protein content can vary with the position of the pod in the plant. If nitrogen level is low and no nodulation occurs, soybeans will contain only 25º/o protein (16).

The effect of temperature on the composition of the seed has received a great deal of attention, mainly with respect to oil content. The effect of minimum temperatures, maximum temperatures, and the delay of planting date are positively related to oil content (13,24). The effects of temperature on the oil content are more evident 20 and 30 days before maturity (25). Late planting date caused a decrease in oil content in late varieties (from 21 to 17º/o); however in some early varieties there was an increase in this trait (26). No effects were obtained in varieties belonging to the intermediate type of maturity (27).

Breeding for oil quality

Several techniques were used to help soybean breeders to select high-oil lines in their programs, mainly in a non-destructive way. Hartwig and Collins (28) using density separation were able to separate high-oil or high-protein seeds, since high-oil seeds presented a lower density in contrast to high-protein ones. Nuclear magnetic resonance is also used to select high-oil seeds (29). Correlations between the chemical components of the leaf and oil and protein contents of the seed were not effective for selection (30).

Variability in oil content within lines was found both among pods in a plant and among plants (23,31). The genotype of the maternal line influenced the oil content in crosses (32,33).

Cowan (34) found that quality of soybean oil is influenced by several factors such as metallic contamination, air, light, and linolenic acid content. A decrease in linolenic acid should increase oil quality; its content varies from 0.3 to 12.1°/o, according to Daubert (12).

Howell and Collins (35) found that temperature causes greater differences in linoleic and linolenic acid, than the genotype. Collins and Sedgwick (36) found that these two fatty acids are increased if varieties are planted north of the area of adaptation.

The iodine number is inversely affected by temperature at the time that oil is synthesized in the seed (35,37).

Variability for fatty acid exists, but very little information is found in the literature concerning their inheritance. Brim, Schutz and Collins (32) found that there is a maternal effect on the inheritance of unsaturated fatty acid content, but in some crosses the male parent genotype influenced the linolenic acid content.

Breeding for protein quality

The nutritional quality of soybean protein is limited by a deficiency in the sulfur-containing amino acids, methionine being the limiting one. Cystine is not an essential amino acid, but will replace methionine to a limited extent (38,39).

In soybeans it has been reported that the 7S portion of the globulin fraction contains only 0.19°/o of methionine (40), indicating that selection for high protein can enhance the methionine deficiency if this portion is increased.

Breeding for high methionine consists in finding genetically determined variability in its content. Alderks (41), found a range for methionine content of 1.28 to 1.53 g/16 g N in 20 varieties. Krober (42) also found variability in the content of this particular amino acid ranging from 1.3 to 1.7 g/16 g N, but there was an influence of location and of planting seasons. Krober and Carter (43) found a range of 1.0 to 1.7 g/16 g N related to protein content. Kakade *et al.* (44) on the other hand, found in 26 varieties a range of 1.0 to 1.9 g/16 g N. There is a positive correlation (0.56 to 0.58) between methionine content and protein content of the seed (43). Kakade *et al.* (44) found that although the total amount of sulfur-containing amino acids is not correlated with the PER, this value improved when varieties were autoclaved at 15 lb/in^2 (120°C) for 30 minutes.

One of the problems is to find a suitable method for determining the methionine content; Kelly, Firman and Adams (45) by modifying the microbiological method have overcome this drawback.

Toxic factors

Several toxic factors have been reported in soybean, but we shall discuss only the trypsin inhibitors.

In 1917 Osborne and Mendel (46) reported that soybeans had to be heated in order to support normal growth in young rats, and in 1945 Kunitz (47) isolated a protein from raw soybeans that formed an inactive complex with trypsin. Liener, Fevold and Devel (48) added methionine to raw soybeans and the nutritive value was remarkably improved, indicating that this protein inhibition affected the availability or utilization of methionine; some uncertainty still remains as to its mode of action and signicance. One point is clear, however; it does cause pancreas hypertrophy (49).

Several trypsin inhibitors were reported in soybeans, but only two were purified and studied in detail: the Kunitz and the Bowman-Birk inhibitors (50,51). Raw seeds contain 1.4% of the Kunitz inhibitor and 0.6% of the Bowman-Birk inhibitor (52).

If trypsin inhibitors are not eliminated, there is a reduction of 50% in the nutritive value. Autoclaving soybeans at 15 lb/in^2 for 10 to 15 minutes generally can inactivate trypsin inhibitors (53). Enough heat treatment is necessary to destroy anti-growth factors but not to decrease protein dispersibility and nitrogen solubility, measured by PDI and SNI values.

Heat can also improve protein efficiency of protein isolates used in textured meals (54), indicating that there possibly is a residue of the growth inhibitor present in the material used.

Kakade *et al.* (44), found a range of 66 to 233 TIU/mg of protein in 108 varieties.

Singh, Wilson and Hadley (55), by means of polycarylamide gel electrophoresis found two types of soybean trypsin inhibitors (SBTI) differentiated by a fast moving band at Rf 0.95 and a slow moving band at Rf 0.92. They suggested that their production is genetically controlled by a single locus with two co-dominant genes, and the fast SBTI is the same as the Kunitz inhibitor or SBTI-A_2. Later Hymowitz and Hadley (56) denominated Ti^1 and Ti^2 the genes that control Rf 0.95 and Rf 0.92 bands, respectively.

Clark, Mies and Hymowitz (57) found that 20 among 294 varieties presented Rf's of 0.92 and the rest presented Rf's of 0.95. The varieties that presented the 0.92 band were of Japanese and Korean origin, but none of them were of Chinese origin.

CONCLUSION

The soybean world production has shown a continuous increase during the last ten years with experimental yields above 3,000 kg/ha in some tropical areas. This potentiality grants an important role to soybeans in this overpopulated area where malnutrition problems are common. Unfortunately, commercial yields are below that value, indicating that more research is needed, mainly in the obtention of adapted varieties and on the use of adequate agronomic practices.

This potentiality is reinforced by its high-protein content which, although presenting a moderate deficiency in methionine, has a lysine content that makes it suitable for use in mixtures with cereals. This is especially meaningful now when cereal production has been increased by the "Green Revolution".

Yield must be the primary objective in any breeding program, but coincidental with it, breeding for high protein, better amino acid balance, and lower content of undesirable factors must be considered. Variability for such purposes exists, but this has to be done as a consequence of improving the biological value of soybeans for human beings in specific local places. This can be achieved by integrated research projects or multidisciplinary programs, where efforts are coordinated to find their maximum nutrive value, digestibility, availability, acceptability and utilization.

Another important factor is to avoid the indirect use of the soybean protein and increase human consumption of the bean. Soybeans can be used as whole beans or as a by-product of oil extraction in a great number of products. Right now, in the developed countries, a great diversity of products are available as a result of a high degree of technology.

RESUMEN

PRODUCCION Y VALOR NUTRITIVO DE LA SOYA

La producción mundial de soya ha venido aumentando a una tasa anual de 5.2°/o (el rendimiento promedio está cerca de 1,400 kg/ha). Esta producción se ha usado solo para extracción de aceite, destinándose la harina desgrasada obtenida, a la alimentación animal, aunque últimamente esta fuente alta de proteína ya está siendo utilizada para consumo humano. Brasil, el tercer productor mundial, ha tenido aumentos anuales de producción de 32°/o en los últimos años. Los promedios de producción en Brasil todavía son bajos (cerca de 1,500 kg/ha), pero en resultados experimentales se han obtenido rendimientos superiores a 3,000 kg/ha. Sin embargo, hay todavía algunos problemas que necesitan ser resueltos, tales como obtención de variedades adaptadas, fertilidad del suelo, prácticas agronómicas adecuadas, y daños por insectos y enfermedades. El contenido de proteína y el de aceite acusan una correlación altamente negativa. Estos dos componentes son condicionados genéticamente y también pueden ser influenciados por condiciones ambientales y prácticas agronómicas. El mejoramiento genético con miras a obtener altos contenidos de proteína (más de 48°/o) trae como consecuencia una reducción en el contenido de aceite y en el rendimiento del grano, pero últimamente se han obtenido nuevas variedades con 43°/o de proteína y una buena capacidad de rendimiento. El contenido de metionina varía de 1.0 a 1.6 g/16 g N, con una correlación de 0.56 a 0.58 entre el contenido de metionina en la proteína y la proteína de la semilla. Se ha puesto bastante atención en los factores tóxicos presentes en la soya, como son los inhibidores de tripsina, ya que su acción se relaciona con la disponibilidad o utilización de la metionina; sin embargo, sus efectos pueden ser eliminados por tratamiento térmico.

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