TECHNICAL

Estimating the Processed Value of Soybeans

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Interest in marketing soybeans on the basis of protein and oil content is increasing. Producers, breeders, handlers and buyers of soybeans need a method of evaluating soybean lots of different composition. A model is presented that predicts, given soybean composition and processing conditions, the yield of crude soybean oil and soybean meal from the processing of soybeans in a solvent extraction plant. From these yields, an estimated processed value (EPV) was calculated. For one set of price conditions, the EPV of typical soybeans had a range of $0.93 per bushel if premiums were paid for meal protein in excess of specifications and a range of $0.53 per bushel if meal protein premiums were not paid. Trading rules established by the National Oilseed Processors Association for domestic meal markets have a significant effect on the value and composition of soybean meal.

Solvent extraction is used almost exclusively for soybean processing (1). Because Congress established in 1986 that end-user value was a key objective of Grades and Standards, new soybean quality tests or Standards should be related to value of end products from solvent extraction processing.

Solvent extraction is a component separation of oil and protein-carbohydrate-fiber (meal). A typical solvent extraction (crushing) operation can be divided into three steps: (i) soybean preparation, (ii) oil extraction and (iii) soybean meal formulation. In the preparation step, the soybeans are cleaned, dried, and cracked into eighths and quarters. The hulls, released from the cotyledons (meats) during cracking, are removed by aspiration. The meats are conditioned to an appropriate temperature and moisture content for subsequent flaking.

In the second step, oil is extracted from the flakes with an organic solvent and reclaimed to yield crude soybean oil. The defatted flakes are desolventized and toasted. The flakes are cooled in preparation for the final step, meal formulation. In step three, the flakes are ground and screened to make soybean meal. Previously separated hulls are usually added to meal to lower the protein content to product specifications. Remaining hulls (mill run) can be traded or saved for future use.

Soybean protein and oil content, along with processing conditions, determine the yield of crude soybean oil and soybean meal per unit of raw soybeans. Higher soybean protein contents allow the processor to include more hulls in the meal while still meeting protein specifications. This results in a greater meal yield. Published crush margins assume that a bushel of soybeans (60 lb) yields 48 lb of 44% protein soybean meal and 11 lb of extracted oil (2). By the model presented here, this assumption corresponds to an average protein and oil content of about 35% and 19% (at 13% moisture), respectively.

A model to predict oil and meal quantiaties from raw soybean composition was first developed by Updaw *et al.* (3). A limited material balance approach was used to calculate product yields over a wide range of protein and oil contents. Linear regression on the resulting yields generated the equations:

$$O_i = -0.62 + 60.72\ X_i \quad (1)$$

$$Y_i = 59.34 - 69.0\ X_i \quad (2)$$

$$Z_{ij} = -0.1343 + 0.6712\ X_i + 1.3203\ X_j \quad (3)$$

where O_i = pounds of oil obtained from a bushel of soybeans; Y_i = pounds of soybean meal obtained from a bushel of soybeans; Z_{ij} = pounds of protein per pound of meal (decimal percent protein); X_i = oil content, expressed as a decimal; and X_j = protein content, expressed as a decimal. These equations assume soybeans at 13% moisture weighing 60 lb/bu, 1.15% total dry-matter loss in the crushing process, a residual oil content in the meal of 1.2% of the meal non-oil dry-matter and a meal moisture of 12%.

The Updaw model does not account for any dehulling, addition of hulls to the meal to control protein content, changes in processing efficiency among different plants or effects of soybean meal marketing practices, such as limitations on the meal fiber content. A more logical approach would be a material balance analysis that allows the inclusion of these factors. Furthermore, if a complete material balance is used, there is no need to determine empirical regression equations.

The oil extraction step was previously modeled by Abraham *et al.* (4) on the basis of a set of material balance and equilibrium equations. This model was developed to aid in equipment selection and to be a guide in determining plant operating conditions. Inputs to the model included mass flow rate of flakes entering the extraction process, miscella/solids equilibrium data and the number of extraction stages or desired residual oil content in the defatted flakes. Although the overall process material balance does not require that the solvent extraction step be modeled in detail, the Abraham model could, if desired, be used to replace the residual oil assumption.

Any computation of meal and oil yields in U.S. solvent extraction plants must include the effect of National Oilseed Processors Association (NOPA) soybean meal trading rules (5). These rules provide voluntary procedures, practices and arbitration protocols for the trading of soybean products. The key provisions with respect to the quantity of soybean meal obtained from a bushel of raw soybeans are:

1. The fiber limitation of 7.0% for 44% protein meal and 3.5% for high-protein (dehulled) meal. The discount for exceeding maximum fiber specifications is 1% of the invoice price per 0.1% fiber in excess of specification. A tolerance of 0.3 percentage points fiber is allowed; and
2. The protein discount of 2 times the unit price of protein per 1% protein below minimum specifications. A tolerance of 0.5 percentage points is allowed.

These rules limit the amount of hulls that can be included in the meal, because exceeding the fiber limit is so costly

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that a processor will choose to "give away" protein in preference to receiving a 10:1 fiber discount. There is no provision for premiums for protein in excess of specifications. Processors will also sell excess hulls as mill run rather than accepting a 2:1 discount on protein, if low protein is a problem. Complete soybean meal specifications can be found in the NOPA trading rules.

If the yield of soybean meal and extracted oil from a lot of soybeans is known, the processed value (the sum of meal, oil and mill run revenues) can be determined from the market prices for soybean meal, crude soybean oil and mill run. Calculation of the processed value of soybeans from protein and oil percentages is a logical extension of soybean composition analysis. Buyers need to know the value of what they are buying and what they can afford to pay. Growers must have the ability to rank varieties and evaluate cultural practices based on anticipated value to the user. Soybean breeders need a meaningful criterion to use in long-term selection programs.

There is considerable variability in the protein and oil content of soybeans (6–8). Soybean buyers are becoming more aware of this variability and how it affects end product yield. For example, export contracts for soybeans shipped to Taiwan now specify minimum protein and oil contents of 35% and 19%, respectively (9). Interestingly, these are the same as those used in the Chicago Board of Trade crush margin statistics. Assuming these percentages to be the long-term U.S. soybean averages, these specifications force soybean shipments to Taiwan to be in the upper half of the distribution in both characteristics.

The domestic soybean market does not openly pay for higher protein and oil contents. If there are to be any direct incentives to grow soybeans of higher protein and oil content, it must be demonstrated that there is significant variability in soybean processed value.

The Federal Grain Inspection Service now includes soybean protein and oil analysis as optional criteria in the U.S. Soybean Standards (10). As protein and oil become more accepted as marketing criteria, traders, growers and plant breeders will need a basis for comparing individual lots. A realistic mathematical model of the inputs to and outputs from solvent extraction processing will provide this information.

The objectives of this study were to: (i) predict the yield of soybean meal, crude soybean oil and mill run from soybeans of known protein and oil content; (ii) determine the processed value from product yields; and (iii) illustrate variability in processed value.

MODEL DEVELOPMENT

End product yield. A model was developed to predict the final yield of soybean meal and crude soybean oil from the processing of a soybean lot. Material balances were written for each of the three systems: (i) soybean preparation, (ii) oil extraction and (iii) meal formulation. Total weight, protein, oil and fiber were accounted for on a dry-matter basis. An input weight basis of 60 lb (one bushel) was used, although other weight units (e.g., kg, tons, metric tons, tons/hr) could be used. Input variables were converted from an "as is" moisture basis to a dry-matter basis for calculations. The yield and composition of end products can be adjusted to any moisture basis. The NOPA trading rules limit the moisture of soybean meal to 12.0%.

A number of processing parameters must be known to predict the yield of soybean meal and oil. They are shown in Table 1. Values for some variables, although probably dependent on soybean composition, were assumed constant because of lack of data. A hull composition of 12% protein, 1.5% oil and 35% fiber (12% moisture basis) was used. Discussions with a regional soybean processor led to the values assumed for this study. A program in Microsoft QuickBasic was written to operationalize the model. The composition and weight of outputs are calculated for each of the three systems: soybean preparation, oil extraction and meal formulation. Input variables to the program are raw soybean moisture, protein, oil and fiber content. Outputs of the program include weights of extracted oil and soybean meal, meal composition and the amount of hulls remaining or added. A block diagram of the model is shown in Figure 1.

Estimated processed value. An estimated processed value (EPV) can be used to approximate the value of products derived from the solvent extraction of soybeans. The EPV of a given lot of soybeans can be calculated from the yield of soybean meal, extracted oil and mill run:

$$EPV = (Pm)(Wm)/2000 + (Po)(Wo) + (Ph)(Whn)/2000 \quad (4)$$

where: EPV = estimated processed value, \$/bu; Pm = meal price, net after any discounts per trading rules,

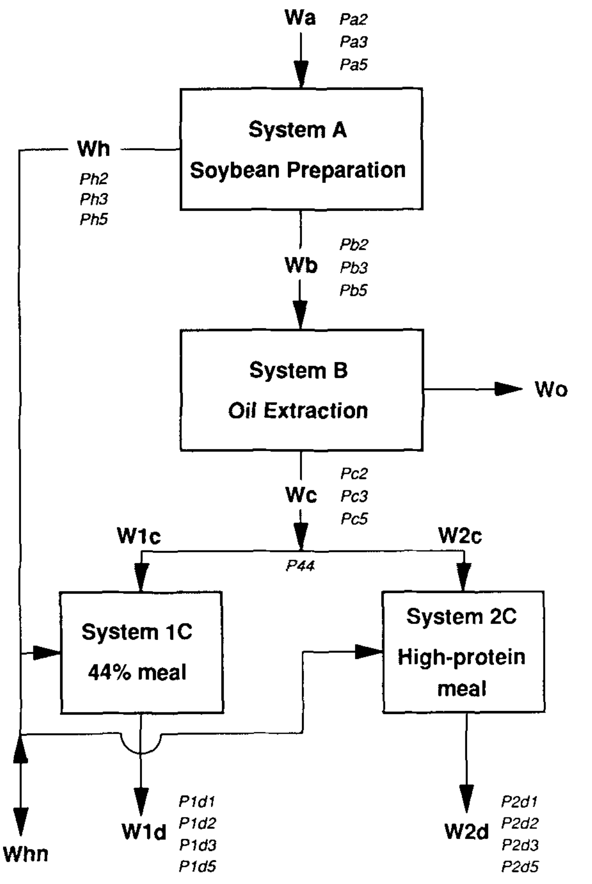

FIG. 1. Block diagram of the mass balance model, showing the production of both 44% protein and high-protein meal.

TABLE 1

Variables and Processing Parameters Used in the Soybean Processing Model

System	Description	Symbol	Units	Assumed values for example
Soybean preparation	Input weight	Wa	lb	60.0
	Hull weight	Wh	lb	—[a]
	Percentage removed by dehulling	Pah	%	10.0
	Hull moisture	Ph1	%	12.0
	Hull protein	Ph2	%	12.0
	Hull oil	Ph3	%	1.5
	Hull fiber	Ph5	%	35.0
	Flake weight	Wb	lb	—[a]
	Flake protein	Pb2	%[b]	—[a]
	Flake oil	Pb3	%[b]	—[a]
	Flake fiber	Pb5	%[b]	—[a]
Oil extraction	Oil weight	Wo	lb	—[a]
	Spent flake weight	Wc	lb[b]	—[a]
	Spent flake protein	Pc2	%[b]	—[a]
	Spent flake oil	Pc3	%[b]	0.5%
	Spent flake fiber	Pc5	%[b]	—[a]
Meal formulation[c]	Hull input weight	Wch	lb	—[a]
	Meal weight	Wd	%	—[a]
	Meal moisture	Pd1	%	12.0
	Meal protein	Pd2	%	—[a]
	Meal oil	Pd3	«	—[a]
	Meal fiber	Pd5	%	—[a]
	Net hulls	Whn	lb	—[a]
	Percentage of 44% vs high-protein	P44	%	100.0
Soybean inputs	Moisture	Pa1	%	Variable
	Protein	Pa2	%	Variable
	Oil	Pa3	%	Variable
	Fiber	Pa5	%	4.4%[d]

[a] Calculated in the mass balance.
[b] Basis 0.0% moisture for calculation purposes only.
[c] Option to produce either 44% meal or high-protein meal or a mix of both.
[d] Basis 13.0% moisture.

\$/ton; Po = oil price, \$/lb; Ph = hull (mill run) price, \$/ton; Wm = weight of soybean meal, lb/bu; Wo = weight of crude soybean oil, lb/bu; and Whn = net weight of hulls (mill run), lb/bu (can be either positive [addition] or negative [removal]).

CASE STUDY SAMPLES

The analyses from 10 samples of soybeans were used to illustrate the variability in estimated processed value. These samples were among 52 entries in the 1987 Iowa State Fair Open Market Soybean Class and were chosen to represent the typical range of protein and oil contents as shown in previous studies (6-8). Protein and oil contents were determined with a Dickey-john Instalab 800 near-infrared (NIR) instrument according to the method described by Hurburgh *et al.* (6). A whole soybean fiber content of 4.4% (13% moisture basis) was assumed (11), although further calibration refinements could permit NIR measurement of actual fiber content.

RESULTS AND DISCUSSION

The end-product yields of the 10 soybean samples are shown in Table 2. Note that samples 1 through 3 must be dehulled to make 44% protein meal. Samples 4 through 10 had enough protein in the whole soybean so that hulls could be added. Dehulling of samples 4-10 would not be necessary to meet 44% protein specifications on the soybean meal. A negative value for Whn means that hulls from other lots could be used, in addition to all the hulls from the lot being processed.

The yield of soybean meal ranged from 42.0 to 51.0 lb/bu. The yield of crude soybean oil ranged from 11.8 to 9.7 lb/bu. This is inconsistent with the published crush margin assumptions of 48 and 11 lb/bu of meal and oil, respectively. Had there been no limit on fiber, samples 8, 9 and 10 would have produced 50.7, 53.1 and 54.1 lb of 44% protein meal per bushel, respectively.

The differences in end product yield are most evident in the estimated processed value (EPV) (Table 3). With a meal price of \$250/ton, a crude soybean oil price of

TABLE 2

End Product Yield for 10 Soybean Samples from the 1987 Iowa State Fair Open Market Class

Sample number	Protein (Pa2) (%)[a]	Oil (Pa3) (%)[a]	Extracted oil (Wo) (lb/bu)	Soybean meal[b] Weight (Wd) (lb/bu)[c]	Soybean meal[b] Protein (Pd2) (%)[d]	Net hulls remaining (Whn) (lb/bu)
1	31.6	20.1	11.8	42.0	44.0	3.9
2	33.1	18.9	11.0	44.6	44.0	2.2
3	33.9	19.0	11.1	46.1	44.0	0.6
4	34.6	18.1	10.6	47.2	44.0	−0.2
5	34.8	19.1	11.2	47.9	44.0	−1.1
6	35.5	18.2	10.6	48.9	44.0	−1.6
7	35.5	17.7	10.3	48.8	44.0	−1.1
8	36.6	17.5	10.2	50.2	44.3	−2.5
9	38.0	16.6	9.7	51.0	45.3	−2.7
10	38.4	17.4	10.1	50.3	46.3	−2.5

[a]Basis 13.0% moisture.
[b]Protein specification of 44%.
[c]Assuming 7.0% fiber maximum. Samples 8-10 limited by fiber specification.
[d]Basis 12.0% moisture.

TABLE 3

EPV for 10 Soybean Samples from the 1987 Iowa State Fair Open Market Soybean Class

Sample	Protein (%)[a]	Oil (%)[a]	Estimated processed value (EPV) ($/bu) Without protein premium	With protein premium
1	31.6	20.1	$8.04	$8.04
2	33.1	18.9	8.15	8.15
3	33.9	19.0	8.32	8.32
4	34.6	18.1	8.32	8.32
5	34.8	19.1	8.52	8.52
6	35.5	18.2	8.52	8.52
7	35.5	17.7	8.44	8.44
8	36.6	17.5	8.57	8.63
9	38.0	16.6	8.54	8.77
10	38.4	17.4	8.57	8.97

[a]Basis 13.0% moisture.

$0.23/lb and a mill run price of $40/ton, EPV was $8.04/bu to $8.57/bu, a range of $0.53/bu. The range expands to $0.93/bu if the protein content of meal limited by the fiber specification was rewarded with a proportionate premium per unit of protein.

Any relationship of EPV to protein or oil content individually, or to the sum of the two, is useful only for specific meal and crude soybean oil prices. The price combination used in this study is a "meal-driven" market—the value of soybean meal is a much greater share of EPV than is the value of crude soybean oil. If different market conditions were encountered (e.g., "oil-driven" or "neutral"), there would be a different relationship between soybean composition and EPV. However, a soybean lot that has higher protein and higher oil content than another will always have the greater EPV, under any price conditions.

A comparison of this model with the Updaw model (3) is presented in Table 4. Samples 1-7 clearly show the effect of no option for dehulling and subsequent addition of hulls to the meal in the Updaw model. The meal protein content varies with the raw soybean composition, without regard to the standard marketing basis of 44%. It is unlikely, for example, that a processor would make soybean meal from sample number 1 without first dehulling. The yields of meal as predicted by the two models are significantly different because the Brumm-Hurburgh (BH) model allows for the blending of mill run into the meal. Additionally, without an option for dehulling in the Updaw model, it is not possible to predict yields for high-protein meal, which cannot be made from soybeans of average composition without dehulling.

The predicted yield of crude soybean oil is higher in the BH model than the Updaw model. This is because Updaw

TABLE 4

A Comparison of Product Yield from Soybean Crushing as Predicted by the Brumm-Hurburgh and Updaw *et al.* (3) Models

Sample	Protein (%)[a]	Oil (%)[a]	Brumm-Hurburgh[b] Oil (lb/bu)	Brumm-Hurburgh[b] Meal[c] (lb/bu)	Brumm-Hurburgh[b] Meal[c] Protein (%)	Updaw *et al.* Oil (lb/bu)	Updaw *et al.* Meal[c] (lb/bu)	Updaw *et al.* Meal[c] Protein (%)
1	31.6	20.1	11.8	42.0	44.0	11.6	45.5	41.8
2	33.1	18.9	11.0	44.6	44.0	10.9	46.3	43.0
3	33.9	19.0	11.1	46.1	44.0	10.9	46.2	44.1
4	34.6	18.1	10.6	47.2	44.0	10.4	46.9	44.4
5	34.8	19.1	11.2	47.9	44.0	11.0	46.2	45.3
6	35.5	18.2	10.6	48.9	44.0	10.4	46.8	45.7
7	35.5	17.2	10.3	48.8	44.0	9.8	47.1	45.3
8	36.6	17.5	10.2	50.2	44.3	10.0	47.3	46.6
9	38.0	16.6	9.7	51.0	45.3	9.5	47.9	47.9
10	38.4	17.4	10.1	50.3	46.3	9.9	47.3	48.9
Averages	35.20	18.21	10.66	47.70	44.39	10.44	46.75	45.30

[a]Basis 13.0% moisture.
[b]Brumm-Hurburgh: 7.0% fiber limitation by NOPA trading rules, hulls added to dehulled meal to obtain 44% protein unless fiber is limiting. Updaw *et al.*: No dehulling or addition of hulls to the meal.
[c]Basis 12.0% moisture.

assumed a higher residual oil content in the meal. Although the BH model could have calculated similar oil yields by using Updaw's specification, this illustrates the inability of the Updaw model to adapt to different processing conditions.

The impact of NOPA trading rules on EPV can be clearly seen in Figure 2 where lines of iso-EPV are plotted vs protein and oil content. These lines were calculated by determining the end product yield and corresponding EPV for all possible combinations of protein and oil content. The slope of the iso-EPV lines is dependent on the ratio of meal to oil prices. As that ratio changes, so does the slope. The values of the iso-EPV lines are determined by the particular prices used.

Soybeans of higher oil content or higher protein content do not categorically have a higher EPV. For example, soybeans containing 37% protein and 16% oil are not as valuable as soybeans containing 34% protein and 21% oil ($8.47/bu vs $8.64/bu). However, under the price conditions presented here, there is a definite advantage in increasing protein over oil. The slope of the iso-EPV line in Figure 2 is approximately −1.25. A unit increase in protein results in a larger EPV than a unit increase in oil. If the slope were exactly −1, protein and oil would have equal value. Slopes less negative than −1 would show an advantage to oil.

As protein content increases, a point is reached where no additional value is gained from higher protein content. The iso-EPV lines become horizontal. Additional value is then determined by an increase in oil content alone. This occurs because of the fiber limitation on soybean meal. The processor cannot add more hulls, resulting in a greater meal yield, without exceeding the fiber specification. Because of the fiber discount, the processor will give away protein if making 44% protein meal from high-protein soybeans. NOPA trading rules (in particular, the lack of a premium schedule for protein in excess of specification) limit the potential for domestic processors to give producers an incentive to grow soybeans of higher protein content. However, processors cannot unilaterally change meal pricing practices because those practices were developed by mutual understanding with the feed industry, consumers of meal.

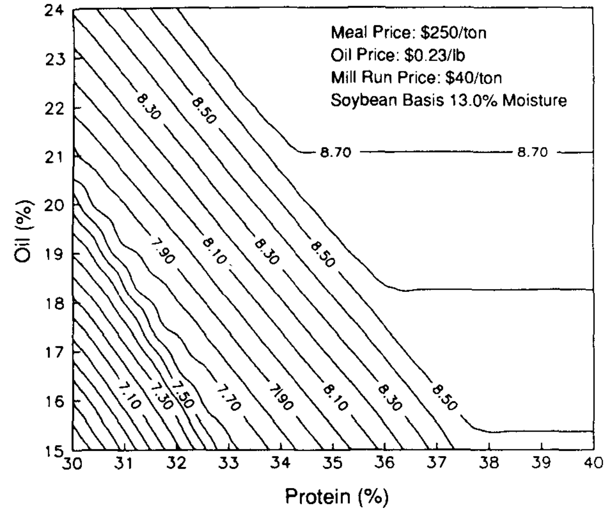

FIG. 2. Iso-EPV lines for soybean protein and oil content based on a specified soybean meal protein of 44%.

As protein content decreases, the iso-EPV lines become closer together. Small changes in protein content have a large effect on EPV. In this range of protein, the processor cannot meet the protein specification and will incur the 2:1 protein discount. There is an area of instability in the iso-EPV lines. This is caused by the tolerance of 0.5 percentage points used when determining whether a protein discount is incurred. A small change in protein content of the meal can cause a disproportionately large change in EPV in this area. For example, meal 0.4 percentage points low in protein would not incur a discount, whereas meal 0.6 percentage points would incur a discount for the full 0.6 points.

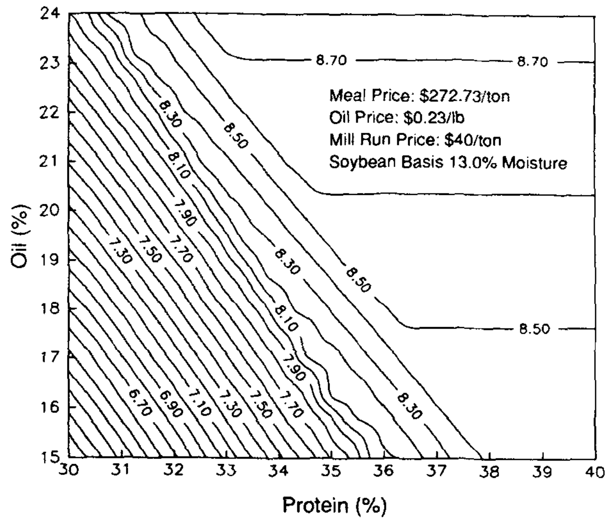

FIG. 3. Iso-EPV lines for soybean protein and oil content based on a specified soybean meal protein of 48%.

A similar pattern of EPV exists when high-protein (48%) meal is made (Fig. 3). The region of closely spaced iso-EPV lines extends to higher protein contents because of the higher meal protein specification. Again, there is a limit on the value of protein in the raw soybean because of premiums for meal protein in excess of specification.

The meal price used to generate Figure 3 (48% protein meal) was the same per unit of protein as Figure 2 (44% protein meal). This is typical of market price differentials between 44% and high-protein meal. For a given protein and oil content, the EPV for 48% meal is lower than the EPV for 44% meal. The processor is unable to sell as much low value mill run as 48% meal because the higher protein specification limits how much can be added to the meal. The key to maximizing EPV is to balance the production of the two meal products so that all hulls are utilized and none need be sold as mill run.

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The computer model described in this paper, with documentation, is available by contacting the authors.

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