THE EFFECTS OF LIQUID BINDERS ON REDUCTION OF PREMIX SEGREGATION AND DUSTINESS

by

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DEDICATION

To **Teodora** and **Jovan Bugarski**

you cared

you loved

you'll always live in my heart

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INTRODUCTION

The primary objective of premix manufacturers is to provide the feed industry with quality products that contain microingredients in relatively high concentrations. A standard of premix quality is that the microingredients be uniformly dispersed in the premix in order to provide desired levels in the finished feeds into which the premixes are added. Any variation of microingredient concentration or uniformity caused by inadequate mixing, improper handling, or any other cause affects the nutrient level in the finished feeds and is a concern of the entire industry -- from the microingredient manufacturers, to the animal nutritionists, to the livestock and poultry producers. Wornick (1985, A) stated that this problem has persisted over 40 years; although, tremendous developments have been achieved in the field of feed manufacturing.

The importance of premix uniformity is critical considering that the mixture of many micronutrients (vitamins, minerals, medication, etc.) will be further diluted hundreds-fold in finished feeds. Separation of premix ingredients due to density, particle size, or shape differences may be expected when the bulk premix is exposed to free-fall as is experienced during mixer discharge, binning, or bulk loadout or when it is subjected to vibration during conveying, bin discharge, or other materials handling in the manufacturing plant or during transportation.

Any such separation of the active ingredients of a premix may be expected to create non-uniformity in the premix and even greater non-uniformity in the finished feeds for which it is intended, thus, failing to meet the prescribed requirements of the animal(s) being fed.

Liquid binders such as vegetable oils have been recommended as agents not only to stabilize a premix physically but also to reduce dust emissions and electrostatic charge build-up. A dusty premix is undesirable because of the potentially harmful effects on the health of workers and loss of active ingredients.

Very little information on the effects of the addition of liquid binders into premixes is available in the literature. The objective of this research was to determine the advantages of the addition of a liquid binder into a premix formulation as a function of a) type of liquid binder applied (soybean oil, mineral oil, choice white grease), and b) application rate (0, 2, 4 percent). Dustiness and uniformity of the premix were measured before and after handling the material through conveying equipment. Uniformity of the premix was monitored by measuring the distribution of selenium, chlorides, niacin, and iodine in the bulk material.

LITERATURE REVIEW

Premixing and Its Necessity in Modern Feed Manufacturing

Development of equipment and automation in the last decade permits concentrated microingredients to be added directly to the mixer of finished feeds. Use of microproportioning systems has many obvious advantages over premixing operations as indicated by McEllhiney (1980):

- Labor and capital investments for premixing are eliminated;
- Potential for equipment and/or human error(s) are reduced if not completely eliminated; and
- Usage records and inventory control can be obtained through the computer printout for each batch.

However, a number of prerequisites have to exist in a feed plant before an automatic micro-proportioning system can be even considered for installation. First, the size of the plant in terms of its annual production capacity -- small plants probably could not justify the capital expenditure. Second, the capability of the mixing equipment to blend small volumes of microingredients and give a uniform product within a reasonable time (Wilcox, 1985).

The classical premix operation can be justified for the following reasons:

- To avoid inadequate weighing or mixing equipment and controls at the finished feed manufacturing location;
- To provide an amount of microingredient component that can be readily handled at the feed mill level (kilograms vs. grams or even smaller units);
- To eliminate the need for multiple weighings and hand-adds at the finished feed mixer; and
- To premix at one location with specialized equipment and more highly qualified personnel and then distribute the product to other locations within a multiple plant operation (McEllhiney, 1980).

The very purpose of the premixing operation is met only if uniform products are manufactured consistently. Uniform products that "provide a balanced diet in each bite," according to Armstrong (1960), are possible only if the microingredients are present in the calculated amount and properly distributed. Pierce (1960) stated that, theoretically, a mixture is completely, i.e. uniformly, mixed when the particles are randomly distributed throughout the premix mass.

Segregation

A non-random arrangement of particles in a mixture of solids is an indication of segregation (Hastings, 1960). Wilcox and Balding (1986) stated that segregation can occur in ingredients as well as in mixed feeds. They defined segregation in ingredients to be the separation of certain fractions or particles from the main mass. In mixed feeds, according to the same authors, segregation occurs when one or more ingredients, or fraction of an ingredient, separate(s) from the remainder of the mix.

Generally, segregation is a common problem when processing and handling bulk solid materials as reported by a number of authors.

Segregation Due to the Properties of Ingredients

Ingredient physical characteristics that may cause segregation are particle differences in size, shape, density, resilience, and air resistance, as well as interaction of particles with each other and with a surface (Carson, 1984). He stated that differences in particle size is the most common mechanism of segregation. This is the sifting of free-flowing fine particles through a matrix of coarse particles in motion. Factors that permit this type of segregation to occur are the ratio of largest to finest particle size of at least 1.5:1, and/or a mean particle size greater than 500 micrometers. Williams and Khan (1973) reported that the diameter ratio and the mean diameter of the components were the prime variables of the mixture that influenced segregation. They found that, at constant diameter ratios of largest to finest particle size (from 1.41:1 to 2.84:1), the segregation tendency of a binary mixture was reduced when the mean diameter of the components was decreased below 500 micrometers.

Other segregation mechanisms caused by differences in particle size were given by Johanson (1978, A):

- Fine materials usually have a higher surface friction than coarser particles of the same material, thus, fines will have lower velocities than coarse particles when sliding on a chute and, consequently, have different deposit distances from the chute;
- Fluidization effect takes place when a mixture of coarse particles and powder enters the airspace of a bin; the powder fluidizes readily while coarse particles pass through. This type of segregation can be minimized by reducing the vertical component of solids velocity;
- Air resistance may affect particles as they fall depending on their size and velocity. Having the same velocity, smaller particles are more affected

than large which results in segregation especially when material falls a long distance;

- Fine particles, having lower resilience than coarse, tend to remain in the center when deposited on a pile;
- Segregation can occur during piling of a mixture of materials having uniform particle size and different angles of repose. The material with a steeper angle of repose tends to remain in the center. Since fines usually have a greater angle of repose than coarse particles of the same material, Johanson (ibid) stated that size segregation by the angle-of-repose mechanism could often be magnified.

If the interaction of particles with each other is sufficiently strong, then segregation does not occur, according to Johanson (ibid), as long as that bond is intact.

Segregation Due to the Handling Equipment

The aforelisted mechanisms of segregation may take place when particles are subjected to motion either by gravity, by conveying, or by free-fall.

Gravity flow of materials out of hoppers and bins has two major types of flow patterns: mass-flow and funnel-flow. Mass-flow is the movement of the whole mass of material in the bin which is, in fact, first-in first-out flow. Some remixing of particles that segregated during bin loading may occur during bin unloading. Funnel-flow, on the other hand, describes the flow that occurs in the center of the bin -- only the material directly above the discharge opening is in motion. Pipes or ratholes can be formed. A potential consequence is a no flow condition when material in the inverted cone at the top of the bin does not move down into the core opening created by funnel-flow. This type of pattern does not give first-in first-out flow and it tends to segregate solids (Colijn, 1975).

Erratic distribution of microingredients may result from conveying due to the capacity of today's feed mills that are designed to manufacture feeds rapidly (Larrabee, 1981). According to the same author (Larrabee, 1976), horizontal conveying by drag conveyors, belt conveyors, or screw conveyors does not affect a properly formulated premix significantly. In addition, he stated that the belt conveyor has the least effect and the screw conveyor the greatest effect on changing a premix composition when it is less-than-optimally formulated. Larrabee (ibid) stated that vertical movement of the premix represented the greatest problem of conveying. Bucket elevators, very often used to elevate the premix, are devastating to a poorly made premix especially those bucket elevators that are oversized and/or run at excessive rates, i.e. create tremendous air streams which fluidize the mix. Even a carefully formulated premix, in Larrabee's opinion (ibid), may lose some of the active ingredients.

A premix that is prone to separate can become non-uniform when subjected just to a single factor -- free-fall through the air. In Larrabee's (ibid) opinion, the negative effects of free-fall are even more greatly increased when a premix contains several components having different densities. The bulky, light particles float away from the main mass and dense particles tend to fall straight down.

Excessive vibration of equipment during handling of a "separation prone" premix may also have negative effects on the quality of the product. Wornick (1985, A) listed major factors causing vibration: suboptimum equipment design, improper installation, wear in component parts and operational factors like partial loads. The use of external vibrators to improve material flow from bagging and loadout bins can also be detrimental according to Wornick (ibid). Similarly, Hamilton (1960) identified vibration of bin or bagger as a possible cause of ingredient separation.

Reduction of Segregation

Although segregation can never be eliminated, according to Johanson (1978, B), a number of authors have recommended techniques to reduce the effects of segregation by application of liquid binders and/or plant and equipment design.

Application of Liquid Binders

For the purpose of this research, liquid binders are defined as different types of oils and fats that help to stabilize premix quality.

Hamilton (1960) felt that the most uniform product could be obtained when fat was added to the feed after the other constituents were blended into a uniform mixture. Armstrong (1960) suggested addition of up to 8% stabilized fat in some cases, but a range from 1 to 4% application rate for usual situations to reduce segregation and the dustiness of premixes. Hasting's study (Hastings, 1960) showed that 1% vegetable oil addition to the carrier helped in reducing small particle segregation. He stated that the presence of a liquid aided in preventing separation of particles that had extreme physical properties. Hastings (1961) explained that particle friction was increased by the addition of vegetable oil and, consequently, segregation of the high density additive was reduced. Wilcox and Balding (1986) recommended use of any technique to reduce differences of ingredients in particle size, shape, and density and thus, reduce the tendency of a mix to segregate. They referred to a commonly used addition of a liquid: molasses, fat, or water to a feed formula. The liquid allows small and large particles to become attached in agglomerates and maintain their homogeneity through subsequent processing and handling. These authors also suggested that dry ingredients should be in a satisfactory mixed state when the liquid is added. Verbeeck (1976) advised addition of a small amount of oil to cereal carriers since it would help to prevent segregation by holding microingredients uniformly in the mix.

Larrabee (1985) stated that there are few premix operations that could not be improved by the addition of a small amount of oil as a binder. Use of a liquid binder not only stabilizes a premix physically by holding the powders uniformly throughout the carrier but also reduces the electrostatic charge that may be present on either the carrier or microingredients (Larrabee, 1976). He recommended use of animal fat or mineral oil in high mineral supplements (Larrabee, 1981) and stabilized unsaturated vegetable oil for premixes with organic carriers and microingredients (Larrabee, 1985). The amount of liquid binder required ranged from 1 to 3% of the total premix weight; however, higher binder levels were required when the end product had a powdery appearance (ibid).

Wornick (1965) reported successful addition of 1 to 3% liquid fat to the premix during blending as well as addition of a low level of mineral oil to high mineral premixes for minimizing ingredient separation.

Addition of liquid binders to premixes has been reported as advantageous for the reduction of electrostatic charge build-up and prevention of microingredient agglomeration since oils and fats are good insulators.

Plant and Equipment Design

Hamilton (1960) recommended that, in a premix operation, equipment should include only the very minimum requirement of bucket elevators and screw conveyors to help reduce the chance of ingredient separation.

To eliminate segregation problems that occur during bin charging, Johanson (1982) recommended either the use of bins with hoppers sloped 75° from the horizontal or use of an insert in the bin with a hopper sloped 45 to 60° from the horizontal. Bins with a hopper sloped 75° from the horizontal promote mass flow and remixing during bin discharge as long as the level of solids in the bin is maintained above the converging hopper portion of the bin. The latter condition cannot be maintained in batch type operations encountered in the feed industry. Hence, a properly designed bin insert would be a better choice for the feed industry providing remixing of the material as well as significant reduction of bin overhead room requirements.

In Wornick's opinion (Wornick, 1985, B), the magnitude of premix segregation that depends on the feed formulation, fineness of grind, liquid levels, bin depth, and other factors can be reduced only partially by increasing liquid levels and minimizing equipment vibration. Bin modifications to reduce free-fall merit consideration, (ibid).

Profiling for Uniformity

Larrabee's procedure to determine uniformity of a batch of feed is to collect a series of at least 10 samples at uniform intervals after the batch had been subjected to mixing and/or conveying. This series of samples is called a "profile", and it is analyzed for a microingredient to indicate uniformity of the material. A satisfactory profile should provide a mean assay value within ±5% of the expected value and a coefficient of variation not greater than 5% (Larrabee, 1981).

The arithmetic mean ($\bar{X}$) of a set of measurements is defined to be the sum of the measurements ($\sum X$) divided by the total number of measurements (n):

$$\bar{X} = \sum X/n$$

Coefficient of variation is the percentage of the mean ($\bar{X}$) that is one standard deviation (s):

$$CV = s/\bar{X} \times 100 \quad \text{or}$$

$$CV = \left\{\left[\sum X^2 - (\sum X)^2/n\right]/(n - 1)\right\}^{0.5}/\bar{X} \times 100$$

where:

$\sum X^2$ - sum of the squares of measurements;

$(\sum X)^2$ - square of the sum of the measurements.

Sampling and Sample Handling

According to several authors, the sampling procedure of feeds and, especially premixes is extremely important; however, varying opinions on this topic have been reported.

According to Wornick (1958), a major consideration is sample size which includes these factors: a) the level of addition of premix to finished feed; b) intended use of the feed; c) batch size; d) sample size required for analysis; e) particle size of the active ingredients and carriers. The sampling point also deserves consideration, since some mixing/segregation is likely to occur at each additional step throughout premix manufacturing. Wornick (ibid) and Poundstone (1960) recommended the use of standard approved sampling devices. However, Hastings (1961) observed samples removed by a probe with the concentration of ingredients differing widely and no evidence of reproducibility. The author's explanation was that the probe was pushing aside particles and permitting segregation as the material filled the probe reservoir.

Pierce (1958) reported satisfactory experience with individual grab samples of premixes. He also pointed out that, after the samples were taken, some care had to be given to sample handling because some premixes could be separated in the sample container by vibration of handling.

Selection of Tracers

The basic criterion for selection of a chemical tracer in feeds is the inclusion rate. If a selected tracer added at low level, proves to be uniform, it is safe to assume that other ingredients, present in larger amounts, have a more-than-equal chance of being uniformly distributed (Larrabee, 1976).

Pierce (1958) stated that, whenever possible, it is preferable to use the analysis for a specific drug or nutrient as a measure of mixing efficiency. Larrabee (1981) pointed out that it is necessary to analyze for a microingredient constituent having a chemical assay procedure with high reproducibility. In Wornick's opinion (Wornick, 1958), a tracer should exhibit physical properties and blending characteristics which are similar to those of the other microingredients in order to provide meaningful results. He divided tracers into four categories: colored materials, compounds determined by chemical tests, fluorescent substances, and radioactive products.

Further literature review will concentrate only on compounds/elements that seemed to be feasible as tracers for the purpose of this research project as well as selected assay procedures.

Selenium

Selenium is an essential nutrient for many species at levels from 0.1 to 0.2 ppm; however, it may be toxic at an inclusion rate of 3 ppm. Due to the toxicity of selenium and its compounds, special care must be taken during the manufacture of premixes that contain this ingredient, and it is desirable to monitor the concentration of selenium routinely by assays.

Microtracer RF-Se[1] contains selenium selenite (Na_2SeO_3) adsorbed on finely reduced elemental iron particles. The selenium concentration is guaranteed to be ±5% of the specification by the manufacturer. Iron particles, being a vehicle of selenium supply to the premix, also provide grounds for a simple, inexpensive, and non-laborious test procedure on the basis of their magnetical property. Although no information is available in the literature on gravimetric retrieval of iron to test for feed uniformity, this proce-

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[1] A product of Micro Tracers, Inc., San Francisco

dure seemed to be promising particularly in premixing operations. The attractiveness of this technique would be justified for the reasons given by Eisenberg (1978):

* Tracer and analysis are inexpensive;

* Results are immediately obtainable at the plant site which is very important when some tests have to be repeated; and

* Analytical interferences are not very likely.

Chlorides

Headley (1967) conducted a study in which chloride titrators were used along with a potentiometric method and a sedimentation technique for assaying the sodium chloride concentration in feedstuffs. He concluded that the chloride titrator method is suitable to measure the degree of mixing when using sodium chloride as the tracer.

The chloride titrator method is based on the measurement of chlorides in a water solution. The titrator is a plastic strip into which a capillary column impregnated with a silver dichromate was laminated. The capillary column absorbs a small quantity of the solution that contains chlorides, and the reaction

$$Ag_2Cr_2O_7 + 2\ Cl^- \text{--->} Cr_2O_7^{2-} + 2\ AgCl$$

occurs producing a white color change. The length of the white color change in the capillary column is proportional to the chloride concentration in the solution.

Choline chloride is a crystalline salt with a high tendency to dissolve and become liquid by absorbing moisture from the air. It is very soluble in water. Choline chloride is assayed by titrating its chlorine content with silver nitrate, and it must contain not less than 25%, and not more than 25.8%, chlorine (Kirk-Othmer, 1965).

The above listed properties of the chloride titrator method and choline chloride represented sufficient evidence in favor of using chlorides as a tracer and conducting this simple and inexpensive test.

Niacin

Niacin, a water soluble crystalline powder, is stable indefinitely in dry form (Wornick, 1968). Niacin stability problems in feeds or premixes have not been reported.

The official AACC method for niacin analysis is quite laborious and involves cyanide bromide -- a toxic agent. The niacin concentration of an extract is determined colorimetrically (Anon., 1987).

High pressure liquid chromatography (HPLC) has become an efficient method for vitamin analysis. Wills et al. (1977) reported successful separation of water soluble vitamins from multivitamin samples. They tested the effects of varying proportions of water/methanol as the eluting solvent, and addition of various salts, buffer solutions, and paired ion chromatography reagents on the retention times of individual vitamins. Zhuge (1985) used the HPLC method to test the storage stability of vitamin A, riboflavin, and niacin in a broiler premix.

Iodine

The stability of soluble iodine compounds (potassium iodide and iodate) in many feed products is a recognized problem due to the effects of moisture, light, oxidation, and incompatibility with acidic materials and metallic salts. In order to achieve improved stability, insoluble iodine compounds are used today in many feed products. One of these is ethylene diamine dihydroiodide (EDDI) (Wornick, 1968).

Given the availability of a nuclear reactor in the Department of Nuclear Engineering on the Kansas State University campus, the unique opportunity of using neutron activation analysis (NAA) for assaying trace minerals was employed. NAA was selected for the analysis of iodine for the following reasons:

- Non-destructive. The integrity of the sample is not changed by any treatments. Thus, contamination or loss due to evaporation is avoided.

- Sensitivity to Trace Elements. Neutron activation analysis is one of the most sensitive methods and is applied to an increasing extent, both in trace analysis and microanalysis (Pinta, 1978).

NAA basically consists of two parts:

1. Selective inducement of radioactivity in some of the elements contained in the sample; and
2. Selective measurement of radiation emitted by the radioactive atoms.

Neutron flux (number of neutrons arriving from all directions and striking the target) and length of irradiation are adjusted so that the atoms of the studied element become as activated as possible; but, on the other hand, atoms of the elements of no interest (sample matrix) stay inactivated as much as possible.

The measurement of radioactivity is based on the fact that, for a given transition, each gamma-ray is emitted with the same energy as a result of nucleus rearrangement. Hence, each radioactive element has its characteristic gamma-ray energy which is base for the identification of several radionuclides at a time. Selectivity of radioactivity measurement can be accomplished through adjustment of the time lapse between the end of irradiation and the start of counting as well as through the length of counting.

Dust Emission

Dust emission occurs as a result of aerodynamic segregation of airborne particles created during handling (moving) of ingredients and finished products in a feed plant. The size of dust particles depends on the nature of the material being subjected to free-fall or great turbulence inside enclosures of equipment. According to Martin (1985), airborne particle emissions can be basically divided into three categories:

- Particles greater than 1 mm are considered trash;
- Particles in the range 0.1 to 1 mm are considered to be coarse dust which settles rapidly and mainly contributes to housekeeping labor; and
- Particles smaller than 0.1 mm are considered to be fine dust which remains suspended in the air for an appreciable time and is carried by air through a facility before settling. In addition to housekeeping labor, the presence of this category of dust contributes to fire and explosion hazards. Also, fine dust contains a fraction of particles smaller than 0.01 mm which are respirable and can represent a health hazard to employees when inhaled.

The importance of dust suppression in premix plants is of particular importance because many active ingredients may be lost through the premix dust and dust collecting systems. Wornick (1985) stated that microingredients, due to their usual fine particle size, may be stripped out of some feed formulas with the dust. He supported this statement with an example: during a survey, dust collector contents showed 28 times higher antibiotic concentration than the medicated feed itself.

Dust Suppressing Liquids as Additives in Grains and Feeds

The reduction of grain dust levels by application of different types of additives has been studied over the years.

Cocke et al. (1978) obtained 59% and 92% reduction of wheat dust levels at 0.04% and 0.07% addition of hydrocarbon-base oil, respectively, under laboratory conditions. They obtained somewhat lower reduction in dust levels of 60% and 80% for soybeans and corn at 0.14% and 0.18% of oil addition.

Jones and Parnell (1985) tested mineral oil for dust suppression in corn, wheat, and soybeans as a function of grain dust levels and the level of oil application. They observed the saturation point with wheat at 0.04% of oil added when further oil addition did not result in an increase of the dust retention characteristics. Corn retained significantly more dust than wheat or soybeans.

Soybean oil and mineral oil were used in a study conducted by Lai et al. (1981) to reduce the dustiness of wheat and corn. They found that the effectiveness of soybean oil in dust suppression diminished with storage time, probably, because the oil was absorbed by the grain kernels. Their results also showed a significant effect on the reduction of dust emission as the application rate of oil was increased. Treatments with mineral oil were more effective than with soybean oil which they attributed to the higher fluidity of mineral oil and its capacity to coat the surface of grain more thoroughly. They also reported a larger average size of dust particles emitted from oil-treated grain than that from the control.

Heber et al. (1986) reported a reduction of dust emission from swine feed by about 20% after addition of 1% of animal fat. Gast and Bundy (1986) tested soybean oil, mineral oil, and lecithin at 0.5, 1.0, and 2% individually and in combination to control aerial dust in premixes. The reported dust reductions on a mass basis were between 76 and 99% depending of the additive type and application rate.

Besides the aforementioned laboratory scale studies conducted to determine dust emission of feeds, a number of papers have reported on successful dust reduction in swine growing-finishing buildings by application of oil additives.

Gore et al. (1986) obtained a 45 to 47% dust reduction in pig nurseries when 5% soybean oil was added to the diet. Similar results were observed in a study conducted by Chiba et al. (1985). Aerial dust in swine growing-finishing buildings was reduced 49% by the addition of 5% tallow into the feed.

Dustiness Measurement

Several methods have been developed to determine dust in grain and feeds prior to its escape into the air. Greenway (1972) developed a fundamental and rapid empirical test for dust in corn. The fundamental method is a gravimetric procedure where the dust is removed from corn by suction and manual shaking, trapped in distilled water, filtered, dried, and weighed to determine percent dust. Results were exact except for dissolved minerals. In the rapid empirical test, the dust separation procedure was the same, but conductivity of the distilled water due to minerals dissolved from the dust was measured instead of weighing the dust. A linear relationship was obtained between conductivity and percent dust.

Separation of dust from grain in Martin's and Lai's (1978) study was accomplished by washing the kernels in isopropyl alcohol. The solution was then filtered, the isopropyl alcohol evaporated, and the dust weight recorded. They found a close correlation between grain dustiness determined by this method and the amount of dust collected during grain handling in a headhouse.

Cocke et al. (1978) conducted dust measurements by agitating 1.8 kg samples of grain in a rotating cylinder, 43 cm in diameter and 68 cm long. Sampling time ranged from 1 to 10 minutes to provide a sufficient amount of dust to adhere onto a membrane filter located inside the cylinder. The concentration of dust in the grain samples was obtained on the basis of the weight of dust accumulated on the filter.

A plywood chamber, 1.2 m by 1.2 m by 1.8 m high, was used to conduct drop tests on 2.3 kg swine premix samples (Gast and Bundy, 1986). The dust cloud was sampled with a particle counter and two volumetric samplers with filter. The premix dustiness was obtained by weighing the filters before and after the drop test.

On the basis of the previous experiences that the drop analysis was related to the dust emission determined during grain handling (Lai et al., 1982), Martin (1985) developed a tester to measure dust emission from 20 g samples of whole corn. The drop tester was designed to simulate aerodynamic segregation of fine dust during grain handling and to contain the dust cloud in a vertical column under laboratory conditions. Dust emission losses were determined on the basis of the difference between the initial sample weight and the weight of the same material 60 seconds after the drop gate of the tester was released and the sample passed through the column.

Heber et al. (1986) modified the abovementioned drop tester in order to simulate the segregation phenomena occurring in livestock buildings and to measure dust emission from feeds. Major changes of this device included the following:

- A gate was installed at the bottom of the column to separate the dust cloud from the catch cup;
- The height of the column was increased;
- A microcomputer was employed to control the operation of the top (drop) and bottom (catch) gates through solenoid actuators in terms of time and sequence;
- The sample size was reduced according to the physical properties of the feed being analyzed (bulk density decrease compared to corn).

EXPERIMENTAL PROCEDURE

Experimental Design

The experiment was designed as a split-plot with two replications of each treatment. The treatments consisted of combinations of three types of liquid binder and two levels of liquid binder additions, and a control. The treatments were assigned to the experimental units (batches of premix according to the randomized complete block design (whole--plot of the split-plot design). The third factor studied in this experiment -- the premix handling -- constituted the sub-plot of the split-plot design since the same premix batch was sampled and measurements taken before and after the premix batch was subjected to this factor (Cochran and Cox, 1950).

Premix Preparation, Handling, and Sampling

The swine premix (Table 1) was formulated for a 400-fold (2.5 kg/m.t.) dilution in finished feeds, and the

TABLE 1 Composition of the Swine Premix

Ingredient	Level of binder		
	Control - 0%	2%	4%
Rice hulls	42.37	40.72	39.06
Calcium carbonate	8.84	8.50	8.15
Liquid binder	0.00	2.00	4.00
Magnesium oxide, 58%	18.63	18.63	18.63
Ferrous sulfate, 31%	10.32	10.32	10.32
Choline chloride, 60%	7.35	7.35	7.35
Zinc oxide, 72%	4.44	4.44	4.44
Manganous oxide, 60%	2.67	2.67	2.67
Niacin technical, 99.5%	1.42	1.42	1.42
Vitamin E, 50%	1.32	1.32	1.32
Calcium pantothenate, 100%	0.77	0.77	0.77
Copper oxide, 75%	0.53	0.53	0.53
Vitamin B_{12}, 2000	0.25	0.25	0.25
Vitamin AD_3, 650/325	0.22	0.22	0.22
Riboflavin, 96%	0.18	0.18	0.18
Vitamin A, 650	0.12	0.12	0.12
Hetrazeen K	0.09	0.09	0.09
Cobaltous carbonate, 46%	0.04	0.04	0.04
Selenium Microtracer[1], 1.16%	0.34	0.34	0.34
EDDI, 79.5%	0.10	0.10	0.10

[1] Micro Tracers, Inc., San Francisco, California

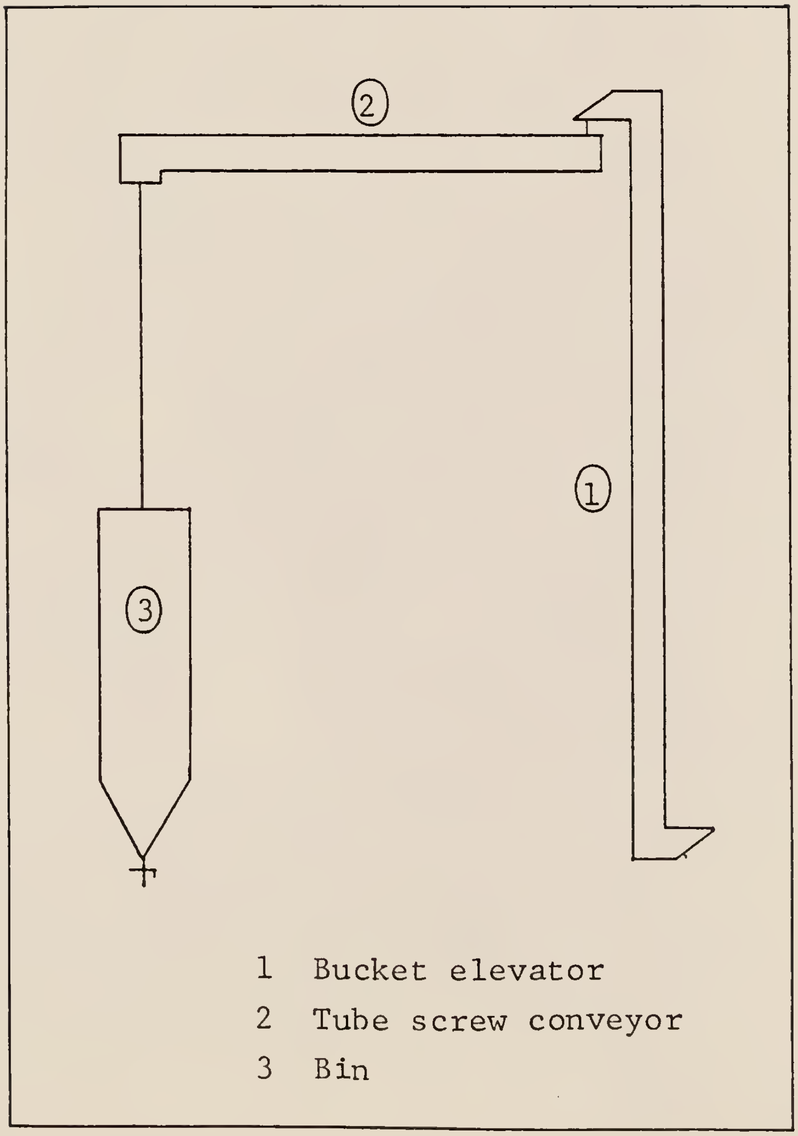

FIGURE 1 Flow Diagram of the Handling Equipment.

preparation procedure was as follows:

- Ingredients for 70 kg batches were weighed on adequate scales depending on the level of inclusion, i.e. a Toledo/8134 scale with 0.02 kg resolution was used for ingredients added at levels higher than 2%; an Ohaus PBI scale with 0.001 kg resolution was used for the ingredients from 0.3 to 2% inclusion rate; and a Mettler PE 6000 balance with 0.1 g resolution was used for ingredients added at less than 0.3%;
- The premix mixer was charged in the following sequence: half of the rice hulls, half of the minerals, vitamins and minerals at 0.25% or less inclusion rate, the rest of the minerals and vitamins, and the balance of the rice hulls;
- A mixing time of five minutes was determined to be sufficient during mixer testing prior to the experiments. Hence, the batch was mixed for five minutes in a Howes Double Flight Ribbon Mixer turning at 53 rpm;
- The liquid binder was sprayed on the top of the material in the mixer at the room temperature except choice white grease that was heated to around 41°C with simultaneous mixing for two or four minutes depending on the level of liquid binder addition;
- After completion of the binder addition, the premix was mixed for an additional five minutes. Thus, 0,

2, and 4% liquid binder required 5, 12, and 14 minutes of mixing time, respectively; and

* The premix was discharged directly from the mixer into 7 kg bags.

Ten 150 g samples were taken from each bag using a bag trier, double tube without compartments, for analyses. These samples will be hereafter referred to as "before handling."

Each batch of the premix was then loaded into a low capacity handling system composed of a bucket elevator 3 m high and a 150 mm tube screw conveyor 2.4 m long from which the material was dropped through a 1.6 m long spout into a bin. The bin hopper was 45° from the horizontal and the distance between the spout and bin outlets was 1.3 m (Figure 1). The premix was passed twice through the system, packaged into 10 bags and sampled again, using the procedure previously given, for analyses. These samples will be further referred to as "after handling."

Measurement of Uniformity

Selenium

Microtracer RF-Se assaying is a gravimetric method based on the magnetic recovery of elemental iron particles from the premix samples.

Equipment used in the assay procedure was (1) a Mettler AC 100 balance with 0.0001 g resolution, (2) a pint mason jar with a special annular magnetic cap, (3) Whatman No. 1 filter paper, 7 cm circles, and (4) a thin fan-tail artist's brush.

A grab subsample of a premix sample of around 5 g was weighed and transferred to the mason jar. The annular magnetic cap was lined with a sheet of filter paper and the jar was closed. The iron particles were attracted to the magnet when the jar was shaken and inverted several times. The cap was then removed and the adhering premix material was separated from the Microtracer by brushing with circular strokes until the Microtracer retained on the filter paper was uniformly grey. Non-magnetic material was discarded while the recovered Microtracer was transferred to a scoop. The steps of retrieving Microtracer from a subsample were repeated three times consecutively which appeared to be sufficient to recover all iron particles. The recovered material was then weighed. Several blank samples of the premix containing no Microtracer RF-Se-1.16% were subjected to the same assay procedure in order to evaluate if other sources of magnetically attractable iron were present. The average background level of iron was 0.026% of the premix weight, i.e. 7.5% of the retrieved iron originated from the background.

Each premix sample was subsampled twice, measurements taken for both, and the average of the two results was taken to be an observation per treatment and replication. The estimated variation between two subsample readings was around 4%.

After the recovered concentration of Microtracer was calculated, the background level of iron was subtracted, thereby providing the basis for reporting the selenium concentration of the samples.

Chlorides

Quantab^R Chloride Titrators were used to conduct fast, inexpensive, and relatively accurate assays. Chlorides present in the swine premix originated from choline chloride, 60% adsorbate. Quantab titrators were not previously used for choline chloride quantification according to the information available in the literature and information obtained from the manufacturer (Friedhofen, 1987). However, due to the complete ionization of choline chloride in an aqueous solution (ibid), it appeared that Quantab^{R} titrators could be used for choline chloride assays. Preliminary tests confirmed this supposition.

Chlorides present in 10 g premix samples, weighed on a Mettler PE 6000 balance with 0.1 g resolution, were extracted with 90 ml of boiling distilled water. Vigorous stirring assured good extraction of chlorides from the samples. Whatman filter paper No. 4 was folded and placed into the extraction solution to collect several drops of filtrate solution inside the cone formed by folding. The lower end of the Quantab^{R} Chloride Titrators No. 1176 were placed in the solution, sufficient time was allowed for the reaction to occur, and the results were read.

Although the obtained results were higher than expected, chloride concentration of the premix background (all ingredients except choline chloride) was not measured due to the limitation of the procedure. The background chloride amount was high enough to affect the test results but not sufficiently high to be determined at the lower end of the Quantab^{R} strip calibration.

Niacin

Being a much simpler and faster procedure than other methods for vitamin analysis, high pressure liquid chromatography (HPLC) was used to measure niacin concentrations in the swine premix samples. The relatively high concentration of niacin as well as the absence of interfering materials in the swine premix were additional factors in favor of HPLC. A Varian Model 5000 liquid chromatograph equipped with a Varichrom Model VUV-10 visible/ultraviolet spectrophotometer was used. Niacin was measured at its maximum absorption wavelength of 262 nm. A Bio-Rad Model 3392A integrator was employed for niacin peak area determinations.

An extract of the swine premix containing all ingredients except niacin was analyzed. No other compound in this premix interfered with the assay at the chosen wavelength.

Extracts of niacin were prepared fresh shortly before HPLC analysis. Grab subsamples of the premix samples were taken and 2 g of the material was weighed on a Mettler PE 360 balance with 0.001 g resolution. The material was placed into Erlenmeyer flasks, and a 200 ml solvent mixture of 30% methanol and 70% water was added and stirred for 30 minutes. Extracts were filtered through Whatman No. 42 filter paper and 0.45 µm syringe filters. Twenty microliter aliquots were applied to a 250 x 4.6 mm Alltech column packed with 5 µm

C-18 octadecylsilyl (ODS) packing material. The analytical column was protected by a guard column packed with the same quality packing. The mobile phase was 30% aqueous methanol, the same as the extraction solvent. All water used in preparation of the mobile phase and extraction solvent was purified by reverse osmosis and then distilled in an all-glass still. The flow rate of the mobile phase was 1 ml min^{-1}. The niacin peak was the only one appearing on a chromatogram with a retention time of around 3 minutes.

Vitamin standards were prepared from the same lot of niacin incorporated into the premix -- niacin technical of 99.5% purity (Lonza, Inc., Animal Nutrition Grade), and were used to determine standard curves each time a set of samples was analyzed. Correlation coefficients for the standard curves, i.e. linear regression lines were all above 0.96. The first replication of the treatments was subjected to the above described method of determination of niacin concentration; however, for the second replication of the treatments, a change in the procedure was necessary due to the noticed instability of the HPLC equipment. In order to eliminate variability of the results caused by the instrument, the standard which contained the expected concentration of niacin was injected prior and after each sample. The determination of the niacin concentration was based on the average response of the instrument for the previous three runs of the standard.

Iodine

Sample preparation for NAA is very simple which reduces the chance of error. Samples of approximately 3.5 g were taken as random grab samples from the sample bags obtained as described earlier. The samples were weighed on a Mettler AC 100 balance with 0.0001 g resolution and encapsulated into polyethylene cylindrical vials shortly after the premix was mixed and/or handled. The vials were heat sealed to prevent any escape of iodine prior to, or during, irradiation due to heat generated within the sample from internal gamma heating. A known weight of iron wire was wrapped around each sample vial for monitoring the neutron flux.

The samples were irradiated in a TRIGA[1] Mark II pulsing nuclear reactor. Due to the short half-life of iodine-128 (25 minutes), the samples were placed manually into the reactor one at a time and irradiated for 5 minutes at 10 kW power that corresponds to neutron flux of 7.2×10^{11} neutrons cm^{-2} s^{-1}.

After irradiation, the samples were taken to the NAA laboratory and counted for 10 minutes by a lithium-drifted-germanium detector. The spectra were analyzed by a

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[1] TRIGA is an acronym for Training-Research-Isotopes-General-Atomic and is a registered trademark of The General Atomic Company.

Canberra Model 8180 multichannel pulse-height analyzer. The iodine peak areas at 442.9 keV were calculated by a microprocessor associated with the analyzer. The same procedure of radioactivity measurement was applied to the flux monitors, and the peak area for the iodine content in a sample was corrected for the fluctuations of the neutron flux during irradiation. This corrected area was later used to calculate the actual concentration of iodine. This was accomplished on the basis of a calibration curve.

The calibration curve was obtained by subjecting standards to the identical activation-decay-counting conditions previously described. The standards were prepared as a mixture of a known iodine quantity at four levels, originating from potassium iodate solution, and sample matrix, i.e., the premix containing all ingredients but EDDI. The correlation coefficient for the calibration curve, i.e., linear regression line was above 0.998. Potassium iodate was selected as a donor of iodine to the standards for its higher solubility in water than EDDI, and for higher stability of iodates in aqueous solutions than iodides.

The sample matrix was also analyzed for iodine and no iodine was detected in this material. Thus, EDDI was the unique source of this element in the premix samples.

Measurement of Dustiness

The effects of liquid binders added at different levels on the reduction of dust emission from the swine premix were tested by the modified drop tester method (Figure 2). This device appeared to be most convenient because of the following factors: small sample size, short time required to conduct the test, and low cost.

For purposes of this experiment, dust emission was defined as the aerodynamic segregation of fine particles in one second from a free-falling 12 g sample of swine premix in a 1 m high, 41 mm diameter column. The average of two dust emissions per treatment and replication was taken as one observation.

The dust emission test consisted of the following steps:

- A grab 12 g subsample was taken from a premix sample, added into a tared plastic cup and weighed on a Mettler AC 100 balance with 0.0001 g resolution;
- The subsample was poured onto the closed top gate of the tester, the top of the cylinder was sealed with a rubber stopper, and the cup was inserted in the bottom of the cylinder;

- The microcomputer program was run, i.e. the gates were operated by the computer in the following sequence; bottom gate open; top gate open and bottom gate closed within a one second time lapse; top gate closed;
- The previous two steps were repeated two more times;
- The cup and the remaining sample were weighed; and
- The cylinder was cleaned with compressed air between tests.

Sample dustiness was calculated as percent mass of the initial sample.

Particle size analyses were conducted on dust samples collected during the drop tests for several treatments (Table 3).

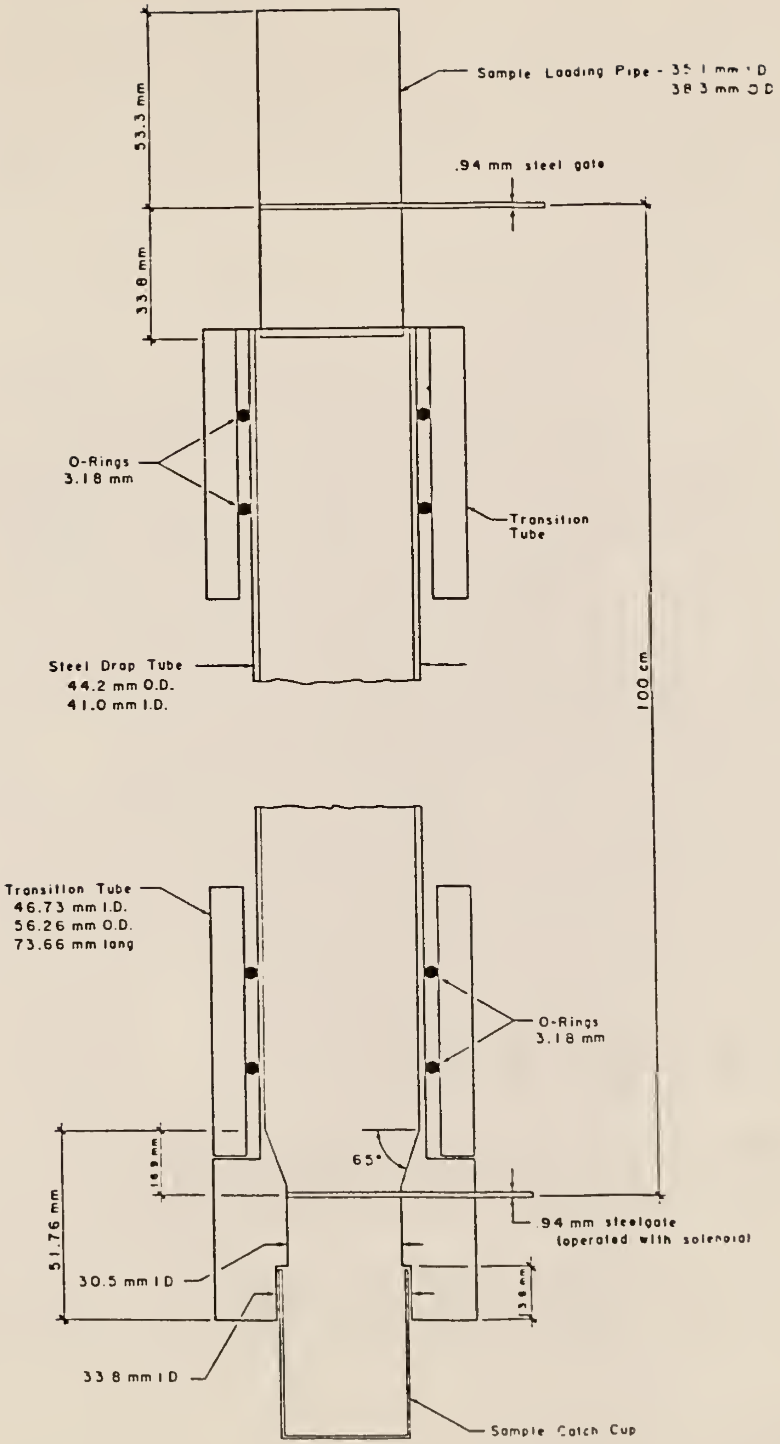

FIGURE 2 Laboratory Drop Tester (Heber et al., 1986).

RESULTS AND DISCUSSION

Liquid Binders

Liquid binders used in this research project were analyzed in a commercial laboratory (Table 2). The samples were submitted for analysis during the progress of the experiments.

As expected, soybean oil showed the highest unsaturation (iodine value) and susceptibility to oxidative rancidity (peroxide value). In fact, the soybean oil had become rancid before it was used for some of the treatments. Although this research was not concerned with the binder rancidity and its negative effects on the stability of fat-soluble vitamins present in the premix -- A, D, E, and K, it must be pointed out that some kind of antioxidants should be used to stabilize unsaturated liquid binders and eliminate the source of oxidizing action in a premix (Wornick, 1985, B).

Mineral oil, having the lowest viscosity at the application temperature(s), was expected to provide the best

TABLE 2 Physicochemical Properties of the Liquid Binders

	Soybean oil	Mineral[1] oil	White grease
Iodine value (g I/100 g binder)	130.5	1.8	64.2
Peroxide value (mE)	10.5	0.9	2.2
Viscosity[2] (cP)			
at 26.7°C	104.5	28.0	-
at 32.2°C	75.0	23.0	-
at 40.5°C	-	-	75.0

[1] Amoco white oil No. 8-T; Amoco Oil Company, Chicago, IL.

[2] Determined by Brookfield Viscosimeter using #1 Spindle at 20 rpm.

coating of the premix particles and, therefore, the best effects on the reduction of segregation and dustiness.

Particle Size Analysis

Particle size analyses of the carriers and selected tracers, as well as several samples of the premix subjected to different treatments and dust collected from those premix samples, are shown in Table 3.

Both components of the carrier system -- rice hulls and calcium carbonate - had adequate geometric mean diameters within the range of 170 to 590 µm as specified by Larrabee (1985). Evidently, the particle size difference between those two ingredients was a compensation for the difference in their densities.

Geometric mean diameters of the tracers show particle size diversity which is unavoidable in premix manufacturing. These values are usually determined by the microingredient manufacturer and represent a balance between distribution requirements, i.e. level of incorporation of a microingredient into a finished feed, and total surface area of the particles that are exposed to adverse chemical effects (Wornick, 1985, B; Verbeeck, 1976). All tracers, even choline chloride which was actually a 60% adsorbate, provided a

TABLE 3 Particle Size Analysis of Ingredients, Swine Premix, and Dust

	Geom. mean dia. (μm)	Geom. mean dia. deviat.	Surface area (cm^2 g^{-1})	Number of particles per gram
Ingredient				
Rice hulls	404	1.58	116.1	27125
Calcium carbonate	222	2.09	130.4	387591
Microtracer™	64	1.56	140.4	1260235
Choline chloride	554	1.47	96.5	9467
Niacin	249	1.29	173.1	60260
EDDI	147	1.78	184.7	538502
Swine premix[1]				
Control	310	1.91	130.4	119360
With 4% soybean oil	335	1.79	118.3	68563
With 2% mineral oil	345	1.64	110.1	40947
With 4% mineral oil	341	1.69	120.4	52326
Dust[2]				
Control	309	1.97	135.7	147567
With 4% soybean oil	246	1.77	169.0	171166
With 2% mineral oil	232	1.92	184.5	316372
With 4% mineral oil	247	1.73	168.2	154315

[1] A blend of "before" and "after handling" samples.

[2] Dust collected from "before" and "after handling" samples.

sufficient number of particles per sample size for analysis to approximate normal distribution:

* Microtracer -- 5 g x 4348 particles/g premix = 21740 particles/sample;
* Choline chloride -- 10 g x 418 particles/g premix = 4180 particles/sample;
* Niacin -- 2 g x 855 particles/g premix = 1710 particles/sample;
* EDDI -- 3.5 g x 538 particles/g premix = 1883 particles/sample.

Particle size analysis of the premix batch containing no liquid binder (control) had the smallest geometric mean diameter and the highest standard deviation of the average particle size. The particle size increase in the premix batches treated with a liquid binder could be attributed to the effects of particle agglomeration. Decreased geometric standard deviation for the batches treated with a liquid binder is, probably, a consequence of agglomeration and an indication of improved premix uniformity. No correlation could be drawn between the effects of the type and level of a liquid binder on the geometric mean diameter of the particles in the premix due to the small number of samples analyzed and the erratic results obtained.

The geometric mean diameter of dust particles collected from the control seemed to be unchanged compared to the average particle size of the control premix. This result was somewhat expected since most of the premix ingredients were powders. In other words, the odds that each particle of the premix could become fluidized during the dust tests were rather high. Hence, the composition of the dust cloud seemed to be identical to the premix composition. The particle size of the dust coming from the premix batches treated with a liquid binder decreased compared to the control dust sample which could be an indication of the formation of agglomerates that could not become fluidized. Although a small number of dust samples were collected and analyzed, it appeared that, as the inclusion rate of a liquid binder increased, the size of dust particles emitted increased as well. This is in accordance with the results reported in the literature (Lai et al., 1981).

Profiling for Uniformity

Selenium

Selenium assay results are reported in Table 4. Ranges of the obtained selenium concentrations (Figure 3) are represented with the lower and the higher value of the two replications.

One-way statistical analysis for the effects of the treatments and handling did not show significant differences

TABLE 4 Selenium Assay Results (10 samples per treatment)[1]

Treatment	Replication 1			Replication 2		
	Mean conc.[2] (ppm)	Range (ppm)	CV (%)	Mean conc.[2] (ppm)	Range (ppm)	CV (%)
Before handling						
Control	40.3	35.5-44.6	5.93	41.2	37.3-46.0	7.00
Soybean oil						
2%	40.7	38.9-43.2	3.27	40.0	38.1-41.9	2.97
4%	39.1	33.4-40.7	5.85	39.3	37.9-40.8	2.32
Mineral oil						
2%	36.6	34.8-38.0	2.88	41.7	40.9-43.4	1.71
4%	39.3	37.2-41.2	3.23	40.7	39.4-43.5	3.05
White grease						
2%	41.1	39.5-42.6	2.70	42.1	39.5-44.0	3.33
4%	37.4	35.7-39.6	3.36	40.1	38.2-41.5	3.06
After Handling						
Control	40.8	31.0-45.5	11.26	40.9	34.4-49.4	13.16
Soybean oil						
2%	38.3	32.9-43.6	10.79	39.6	36.4-44.3	6.94
4%	39.4	36.2-44.1	5.54	39.6	35.1-43.9	7.83
Mineral oil						
2%	39.4	36.2-46.6	8.04	40.4	32.6-44.9	9.41
4%	36.7	33.4-40.5	7.26	38.3	32.1-47.9	11.43
White grease						
2%	39.5	31.9-46.1	10.77	40.9	33.7-47.4	11.64
4%	38.3	35.7-41.2	5.41	40.7	36.5-42.7	4.60

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[1] Selenium concentration is a calculated value on the basis of the specifications of the manufacturer of Double Strength Microtracer RF-Se-1.16%.

[2] Expected selenium concentration was 40 ppm.

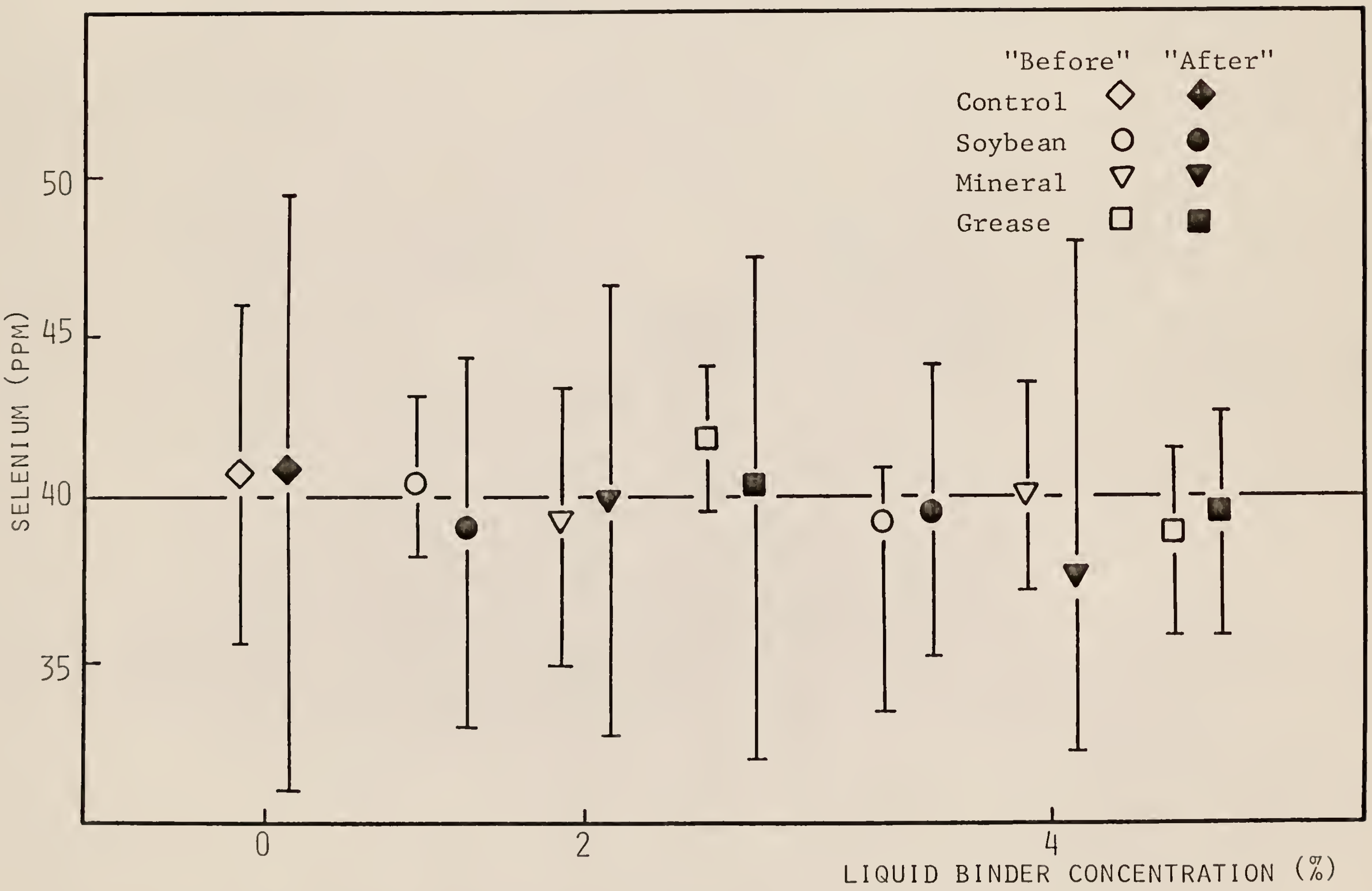

FIGURE 3 Ranges and Means of Selenium Concentrations as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

among selenium mean concentrations (Tables 5 and 6, respectively). Coefficient of variation for the control was significantly higher than for the other treatments except for the premix treated with 2% white grease which is, generally, an indication of positive effects of the application of liquid binders. Segregation of the premix was significantly increased by handling.

Although no significant uniformity differences among premix batches treated with liquid binders were determined by the two-way analysis, some trends were evident. It appeared that mineral oil had the poorest performance and white grease the best in retarding segregation of selenium (Table 7). The premix non-uniformity tended to decrease as the level of the liquid binders was increased (Table 8). Handling effects were still significant on premix segregation; although, the control was not taken into consideration (Table 9). This can be attributed to the 2% inclusion rate of the liquid binders (Table 10). Two percent of binder present in the premix seemed to be insufficient to hold the particles together and retard segregation of selenium during handling. Interestingly, the coefficient of variation for the batches "before handling" and at the 4% application rate of liquid binders increased slightly compared to the lower application rate of the binders (Figure 4). This would indicate that a saturation point was reached somewhere between these two points; however, only mineral oil showed the same

TABLE 5 Selenium Distribution in the Swine Premix as Affected by Treatments (One-Way Analysis)[1,2,3]

Treatment	Mean concentration (ppm)	Coefficient of variation (%)
Control	40.8^{a}	9.34^{c}
Soybean oil		
2%	39.6^{a}	5.99^{ab}
4%	39.4^{a}	5.38^{ab}
Mineral oil		
2%	39.5^{a}	5.51^{ab}
4%	38.8^{a}	6.24^{ab}
White grease		
2%	40.9^{a}	7.11^{bc}
4%	39.1^{a}	4.11^{a}

[1] Values are means of 4 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

[3] See footnote 1, Table 4.

TABLE 6 Selenium Distribution in the Swine Premix as Affected by Handling (One-Way Analysis)[1,2,3]

Handling	Mean concentration (ppm)	Coefficient of variation (%)
Before	39.9^{a}	3.62^{a}
After	39.5^{a}	8.86^{b}

[1] Values are means of 14 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

[3] See footnote 1, Table 4.

TABLE 7 Selenium Distribution in the Swine Premix as Affected by Type of the Liquid Binder (Two-Way Analysis)[1,2]

Type	Mean concentration (ppm)	Coefficient of variation (%)
Soybean oil	39.5	5.69
Mineral oil	39.1	5.88
White grease	40.0	5.61

[1] Values are means of 8 observations. Means within a column are not significantly different ($P<0.05$).

[2] See footnote 1, Table 4.

TABLE 8 Selenium Distribution in the Swine Premix as Affected by Level of the Liquid Binder (Two-Way Analysis)[1,2]

Level (%)	Mean concentration (ppm)	Coefficient of variation (%)
2	40.0	6.20
4	39.0	5.24

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

[2] See footnote 1, Table 4.

TABLE 9 Selenium Distribution in the Swine Premix as Affected by Handling (Two-Way Analysis)[1,2,3]

Handling	Mean concentration (ppm)	Coefficient of variation (%)
Before	39.8^{a}	3.14^{a}
After	39.2^{a}	8.30^{b}

[1] Values are means of 12 observations.

[2] Means with the same letter within a column are not significantly different (P<0.05).

[3] See footnote 1, Table 4.

TABLE 10 Coefficient of Variation (%) of Selenium as Affected by the Interaction Liquid Binder Level - Handling (Two-Way Analysis)[1,2,3]

Level	Handling	
(%)	Before	After
2	2.81^{A,a}	9.60^{A,b}
4	3.48^{A,a}	7.01^{A,a}

[1] Values are means of 6 observations.

[2] Means with the same letter are not significantly different (P<0.05). Labels with capital letters refer to the means within a column, and labels with small letters refer to the means within a row.

[3] See footnote 1, Table 4.

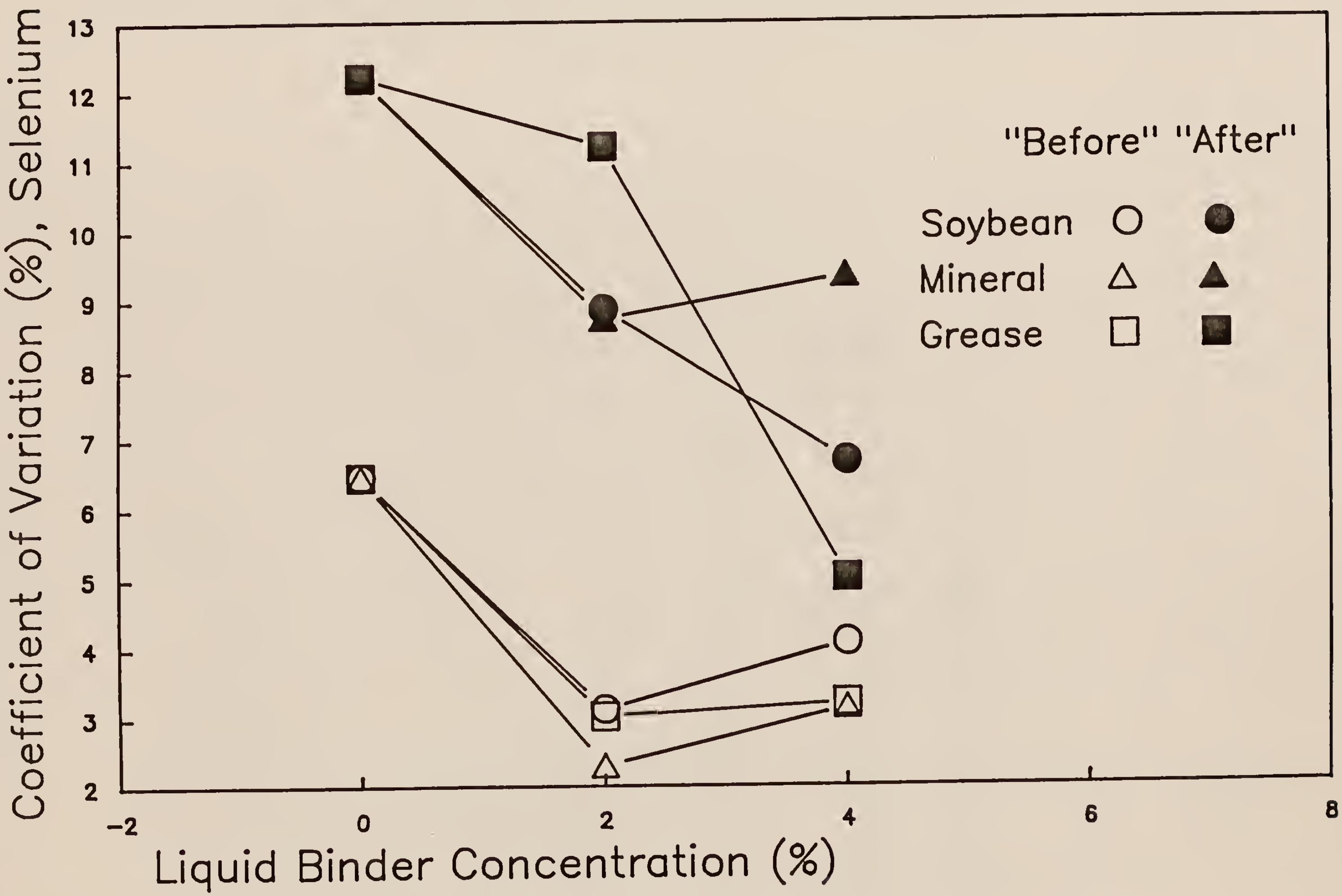

FIGURE 4 Uniformity of Selenium Distribution as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

trend after the premix was subjected to handling. Higher amounts of soybean oil and white grease in the premix appeared to withstand segregation forces without significant effects on premix quality.

As indicated in Table 11, the mean concentrations of selenium for the premix batches containing mineral oil at 4% were significantly different "before" and "after handling" for an unknown reason.

Chlorides

Chloride assay results (Table 12) were somewhat erratic. Figure 5 illustrates the obtained means of chloride concentrations (including the background) as well as the ranges.

The effects of the treatments were not significant (Table 13) and, moreover, the control was better than the premix batches subjected to some of the treatments in terms of uniformity. The coefficient of variation was significantly increased by handling (Table 14).

Mineral oil appeared to have the lowest ability to resist segregation among the types of binders used (Table 15); although, the differences were not significant. Increasing the liquid binder level from 2 to 4% gave almost negligible change of the coefficient of variation (Table 16). The mean concentration of chlorides in the samples "before handling"

TABLE 11 Mean Concentration of Selenium (ppm) as Affected by the Interaction Liquid Binder Type -- Liquid Binder Level -- Handling (Two-Way Analysis)[1,2]

Type - Level	Handling	
	Before	After
Soybean oil		
2%	40.3^{a}	39.0^{a}
4%	39.2^{a}	39.5^{a}
Mineral oil		
2%	39.2^{a}	39.9^{a}
4%	40.0^{b}	37.5^{a}
White grease		
2%	41.6^{a}	40.2^{a}
4%	38.8^{a}	39.5^{a}

[1] Values are means of 2 observations.

[2] Means with the same letter within a row are not significantly different ($P<0.05$).

TABLE 12 Chloride Assay Results (10 samples per treatment)

Treatment	Replication 1			Replication 2		
	Mean conc.[1] (%)	Range (%)	CV (%)	Mean conc.[1] (%)	Range (%)	CV (%)
<u>Before handling</u>						
Control	1.44	1.38-1.52	3.54	1.37	1.33-1.42	1.99
Soybean oil						
2%	1.42	1.28-1.47	4.64	1.35	1.18-1.42	7.16
4%	1.48	1.38-1.69	6.32	1.45	1.28-1.60	7.37
Mineral oil						
2%	1.45	1.23-1.52	6.83	1.48	1.38-1.60	4.54
4%	1.43	1.38-1.52	2.94	1.50	1.42-1.60	3.58
White grease						
2%	1.50	1.47-1.52	1.54	1.36	1.18-1.52	8.32
4%	1.51	1.42-1.60	3.10	1.44	1.33-1.52	3.91
<u>After Handling</u>						
Control	1.36	1.14-1.52	9.27	1.38	1.28-1.52	5.85
Soybean oil						
2%	1.43	1.38-1.52	3.46	1.41	1.33-1.47	3.61
4%	1.40	1.14-1.52	7.42	1.41	1.23-1.52	5.50
Mineral oil						
2%	1.38	1.14-1.52	9.92	1.35	1.14-1.52	9.83
4%	1.34	1.14-1.42	7.36	1.37	1.14-1.52	9.27
White grease						
2%	1.45	1.38-1.52	3.88	1.41	1.23-1.52	6.16
4%	1.38	1.14-1.52	7.36	1.43	1.33-1.47	3.46

[1] Expected concentration of chlorides was 1.16%.

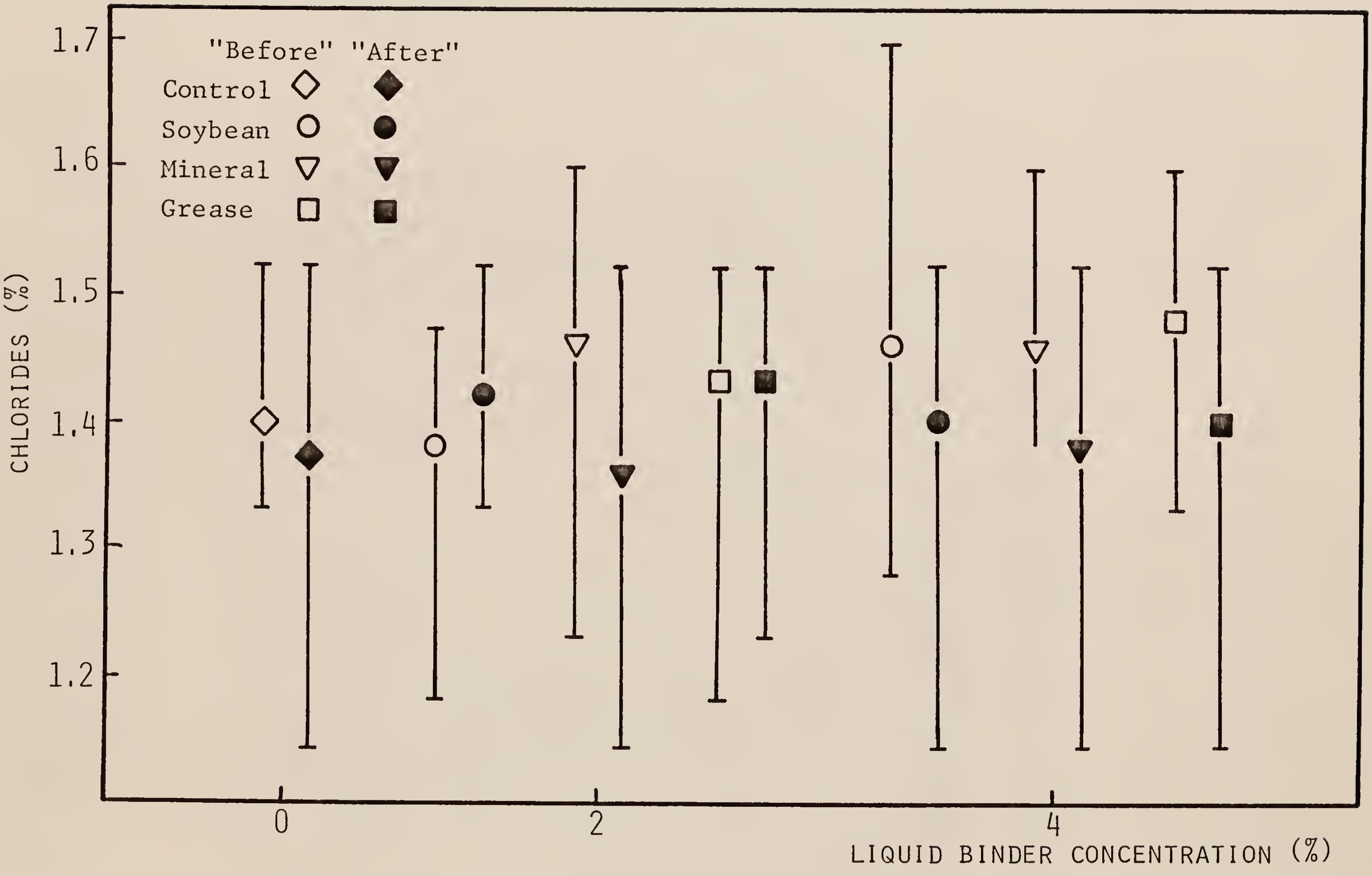

FIGURE 5 Ranges and Means of Chlorides Concentrations as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

TABLE 13 Chloride Distribution in the Swine Premix as Affected by Treatments (One-Way Analysis)[1]

Treatment	Mean concentration (%)	Coefficient of variation (%)
Control	1.39	5.16
Soybean oil		
2%	1.40	4.72
4%	1.44	6.65
Mineral oil		
2%	1.41	7.60
4%	1.41	5.79
White grease		
2%	1.43	4.98
4%	1.44	4.46

[1] Values are means of 4 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 14 Chloride Distribution in the Swine Premix as Affected by Handling (One-Way Analysis)[1,2]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	1.44^b	4.70^a
After	1.39^a	6.55^b

[1] Values are means of 14 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

TABLE 15 Chloride Distribution in the Swine Premix as Affected by Type of the Liquid Binder (Two-Way Analysis)[1]

Type	Mean concentration (%)	Coefficient of variation (%)
Soybean oil	1.42	5.68
Mineral oil	1.41	6.70
White grease	1.44	4.72

[1] Values are means of 8 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 16 Chloride Distribution in the Swine Premix as Affected by Level of the Liquid Binder (Two-Way Analysis)[1]

Level (%)	Mean concentration (%)	Coefficient of variation (%)
2	1.43	5.76
4	1.42	5.63

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

was significantly higher than in the samples "after handling" (Tables 14 and 17). The cause of this difference is unknown.

Handling caused significant segregation of the chlorides in the batches treated with mineral oil and white grease, and an unexpected increase in the uniformity of the batches treated with soybean oil (Table 18). Presumably, the latter was a result of some remixing that occurred during handling. The ultimate quality of the premix, based on the uniformity of dispersion of chlorides and type of the liquid binder, could be ranked as follows: soybean oil followed by white grease. The treatments with mineral oil did not show any advantages over the control in the range of the inclusion rates tested (Figure 6). The other two binders, on the other hand, appeared to reach the saturation point between the 2 and 4% addition levels when a further increase of the binder content in the premix did not result in improvement of its uniformity. The somewhat unexpected results obtained for chlorides could be attributed to the very high hygroscopicity of choline chloride -- the source of chlorides -- and to the immiscibility of water drawn from the air and the liquid binder applied to the premix.

TABLE 17 Chloride Distribution in the Swine Premix as Affected by Handling (Two-Way Analysis)[1,2]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	1.45^{b}	5.02^{a}
After	1.40^{a}	6.38^{a}

[1] Values are means of 12 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

TABLE 18 Coefficient of Variation (%) of Chlorides as Affected by the Interaction Liquid Binder Type -- Handling (Two-Way Analysis)[1,2]

Type	Handling	
	Before	After
Soybean oil	6.37^{B,c}	5.00^{A,a}
Mineral oil	4.47^{A,b}	8.92^{B,c}
White grease	4.22^{A,a}	5.22^{B,b}

[1] Values are means of 4 observations.

[2] Means with the same letter are not significantly different ($P<0.05$). Labels with capital letters refer to the means within a row, and labels with small letters refer to the means within a column.

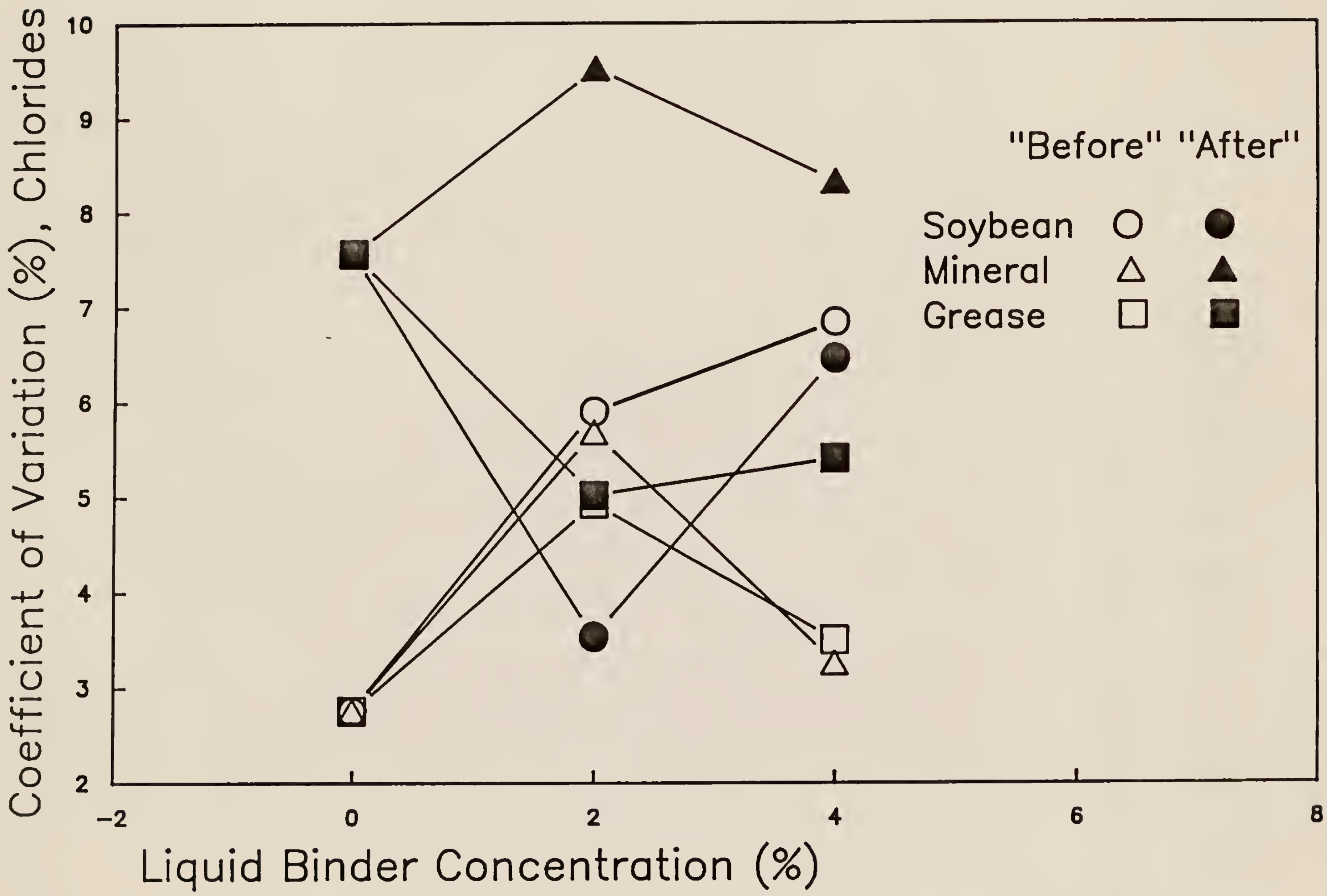

FIGURE 6 Uniformity of Chlorides Distribution as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

Niacin

Niacin assay results (Table 19) are followed by a diagram of the obtained mean concentrations of the recovered - vitamin with maximum and minimum values for each set of ten samples (Figure 7).

Uniformity of niacin dispersion, measured by the coefficients of variation, was not significantly affected by the application of liquid binders (Table 20); however, there was evidence that premix quality was slightly improved compared to the control. Repeatedly, handling was a significant cause of premix segregation (Table 21).

White grease appeared to be the most effective agent for retarding segregation of niacin though not significantly different than the other liquid binders tested (Table 22). The four percent application rate of the binders seemed to be advantageous over two percent (Table 23). Significant differences of the coefficient of variation between "before" and "after handling" batches of the premix treated with the binders indicated that the interaction of niacin particles with the binders was not sufficiently strong to resist segregation.

The significant difference between mean concentrations of niacin "before" and "after handling" of the premix batch-

TABLE 19 Niacin Assay Results (10 samples per treatment)

Treatment	Replication 1			Replication 2		
	Mean conc.[1] (%)	Range (%)	CV (%)	Mean conc.[1] (%)	Range (%)	CV (%)
<u>Before handling</u>						
Control	1.33	1.25-1.40	2.92	1.54	1.22-1.80	10.53
Soybean oil						
2%	1.56	1.47-1.65	6.52	1.48	1.35-1.66	6.11
4%	1.62	1.46-1.79	6.15	1.46	1.30-1.67	6.69
Mineral oil						
2%	1.36	1.21-1.44	5.53	1.61	1.38-1.79	7.20
4%	1.72	1.64-1.79	2.94	1.46	1.29-1.66	6.86
White grease						
2%	1.59	1.50-1.82	5.41	1.48	1.25-1.69	9.42
4%	1.32	1.21-1.47	7.00	1.49	1.38-1.68	6.48
<u>After Handling</u>						
Control	1.25	1.10-1.40	8.40	1.51	1.10-1.83	14.47
Soybean oil						
2%	1.49	1.24-1.63	9.39	1.51	1.06-1.73	12.99
4%	1.69	1.61-1.85	5.25	1.41	1.01-1.65	13.06
Mineral oil						
2%	1.29	1.18-1.35	3.35	1.46	1.18-1.69	11.84
4%	1.73	1.42-2.01	10.21	1.53	1.26-1.86	12.11
White grease						
2%	1.58	1.46-1.75	6.50	1.56	1.36-1.78	9.65
4%	1.22	1.13-1.36	6.19	1.42	1.33-1.50	4.18

[1] Expected niacin concentration was 1.42%.

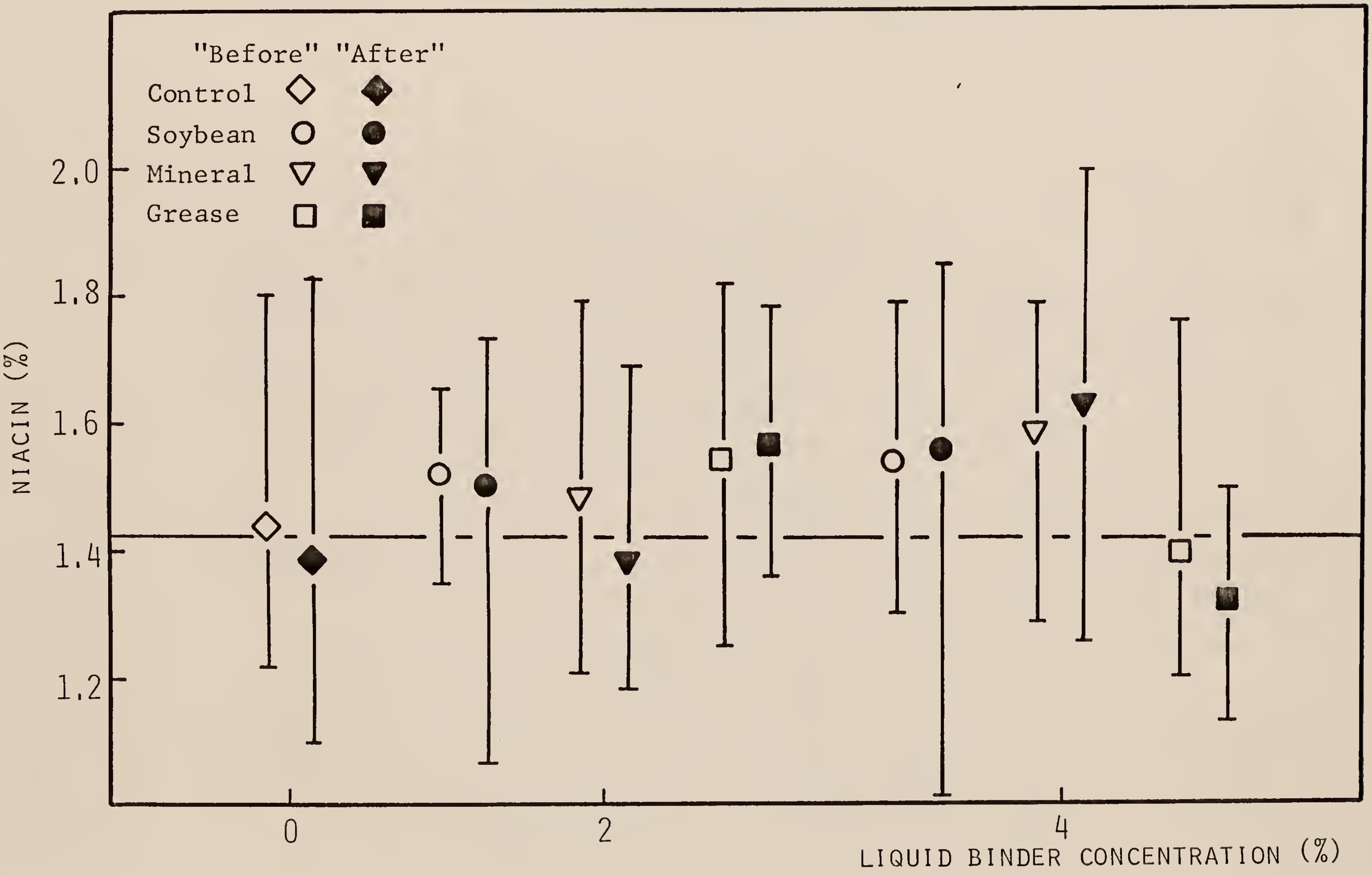

FIGURE 7 Ranges and Means of Niacin Concentrations as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

TABLE 20 Niacin Distribution in the Swine Premix as Affected by Treatments (One-Way Analysis)[1]

Treatment	Mean concentration (%)	Coefficient of variation (%)
Control	1.41	9.08
Soybean oil		
2%	1.51	8.75
4%	1.54	7.79
Mineral oil		
2%	1.43	6.98
4%	1.61	8.03
White grease		
2%	1.55	7.74
4%	1.36	5.96

[1] Values are means of 4 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 21 Niacin Distribution in the Swine Premix as Affected by Handling (One-Way Analysis)[1,2]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	1.50^{a}	6.41^{a}
After	1.48^{a}	9.11^{b}

[1] Values are means of 14 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

TABLE 22 Niacin Distribution in the Swine Premix as Affected by Type of the Liquid Binder (Two-Way Analysis)[1]

Type	Mean concentration (%)	Coefficient of variation (%)
Soybean oil	1.53	8.27
Mineral oil	1.52	7.51
White grease	1.46	6.85

[1] Values are means of 8 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 23 Niacin Distribution in the Swine Premix as Affected by Level of the Liquid Binder (Two-Way Analysis)[1]

Level (%)	Mean concentration (%)	Coefficient of variation (%)
2	1.50	7.82
4	1.50	7.26

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 24 Niacin Distribution in the Swine Premix as Affected by Handling (Two-Way Analysis)[1,2]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	1.51[a]	6.36[a]
After	1.49[a]	8.73[b]

[1] Values are means of 12 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

es treated with 2% mineral oil (Table 25) could be justified by the noticed instability of the HPLC previously described.

Although the results for premix uniformity treated with white grease before handling did not seem to be advantageous over the control (Figure 8), the final quality of the premix was, evidently, improved. The premix with 4% white grease after handling consistently showed better uniformity than before it was subjected to handling probably due to some remixing in the conveying line.

Iodine

Iodine assay results are shown in Table 26. Figure 9 illustrates the ranges of iodine results for each treatment before and after the premix was handled where the low and high values represent the minimal and maximal iodine concentrations obtained for two replications, respectively.

All treatments of the premix with liquid binders appeared to improve uniformity of the material over the control although not significantly (Table 27). Uniformity of the premix was negatively and significantly affected by the postmixer handling as indicated by the coefficients of variation (Table 28). The significantly lower mean iodine concentration after handling than before handling was probably caused by the low level of incorporation of this ingredient

TABLE 25 Mean Concentration of Niacin (%) as Affected by the Interaction Liquid Binder Type -- Liquid Binder Level -- Handling (Two-Way Analysis)[1,2]

Type - Level	Handling	
	Before	After
Soybean oil		
2%	1.52^a	1.50^a
4%	1.54^a	1.55^a
Mineral oil		
2%	1.48^b	1.38^a
4%	1.59^a	1.63^a
White grease		
2%	1.54^a	1.57^a
4%	1.40^a	1.32^a

[1] Values are means of 2 observations.

[2] Means with the same letter within a row are not significantly different ($P<0.05$).

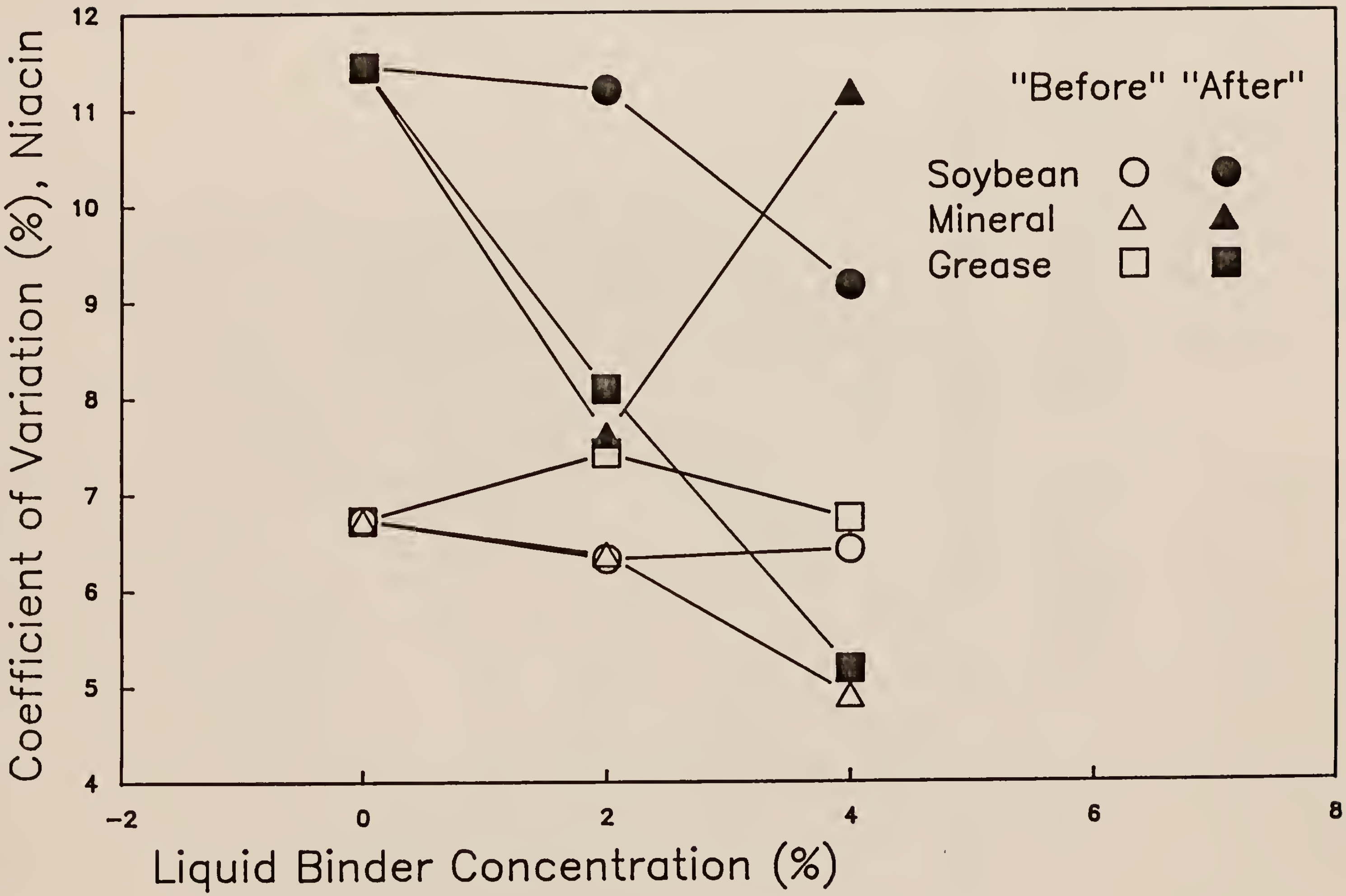

FIGURE 8 Uniformity of Niacin Distribution as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

TABLE 26 Iodine Assay Results (10 samples per treatment)

Treatment	Replication 1			Replication 2		
	Mean conc.[1] (ppm)	Range (ppm)	CV (%)	Mean conc.[1] (ppm)	Range (ppm)	CV (%)
Before handling						
Control	853	734-1035	11.35	659	494- 793	14.60
Soybean oil						
2%	720	610- 875	13.43	879	669-1022	13.59
4%	721	628- 804	9.13	892	636-1072	15.09
Mineral oil						
2%	783	649- 975	12.50	696	574- 859	12.41
4%	873	765-1070	11.06	864	775-1023	9.92
White grease						
2%	778	657- 925	12.39	744	646- 858	11.79
4%	836	662- 951	13.01	887	710-1099	16.23
After Handling						
Control	824	580-1053	18.03	596	437- 766	18.89
Soybean oil						
2%	713	416- 946	19.24	878	700-1088	13.01
4%	658	412- 809	18.24	844	701- 977	10.25
Mineral oil						
2%	733	581- 881	15.09	664	474- 801	16.67
4%	904	754-1281	17.80	876	643-1039	12.30
White grease						
2%	733	526- 929	16.71	749	573- 951	17.57
4%	673	524- 817	16.34	895	722-1149	13.02

[1] Expected iodine concentration was 826 ppm.

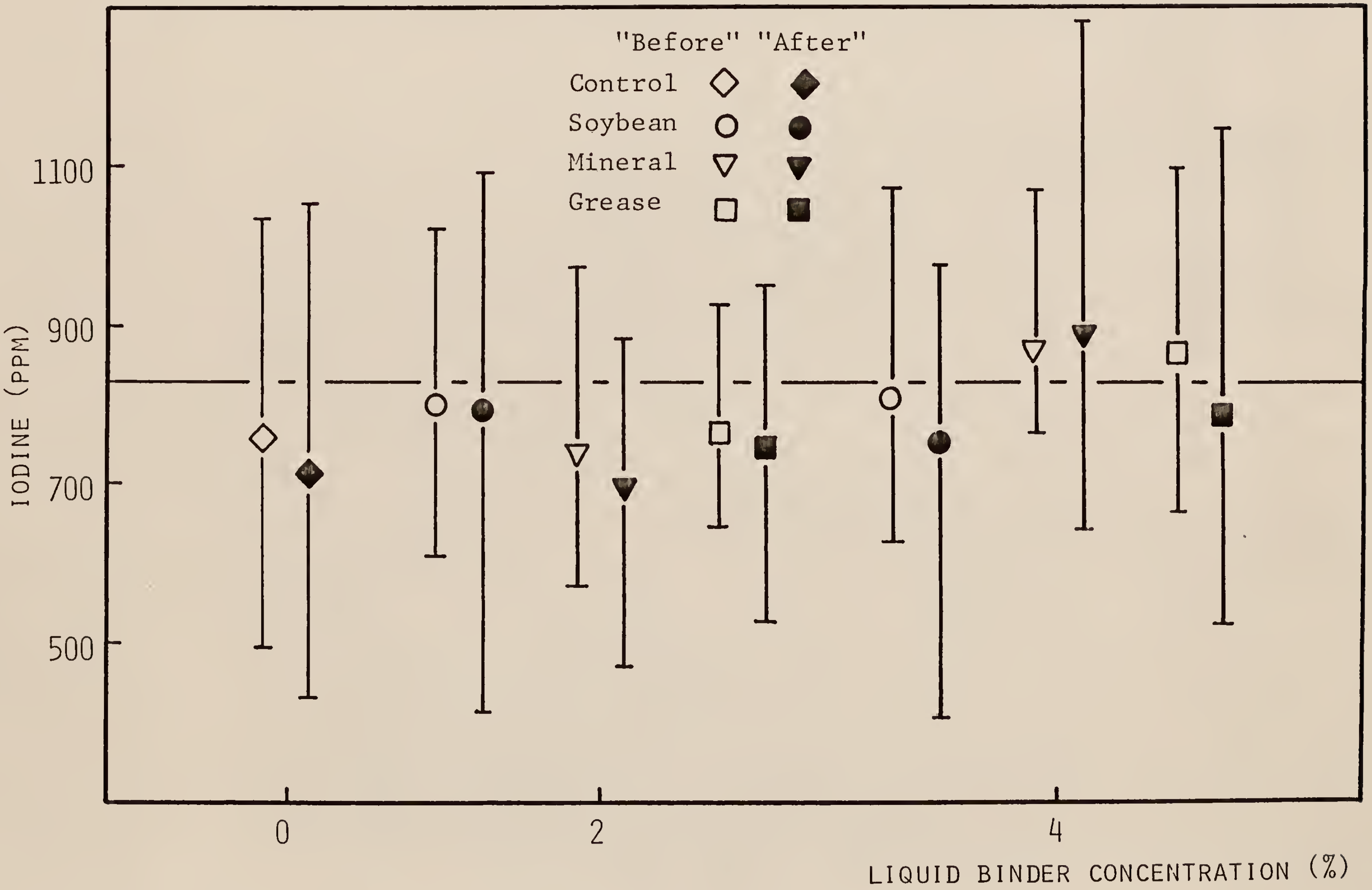

FIGURE 9 Ranges and Means of Iodine Concentrations as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

TABLE 27 Iodine Distribution in the Swine Premix as Affected by Treatments (One-Way Analysis)[1]

Treatment	Mean concentration (ppm)	Coefficient of variation (%)
Control	733	15.72
Soybean oil		
2%	798	14.82
4%	779	13.18
Mineral oil		
2%	719	14.17
4%	879	12.77
White grease		
2%	751	14.62
4%	823	14.65

[1] Values are means of 4 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 28 Iodine Distribution in the Swine Premix as Affected by Handling (One-Way Analysis)[1,2]

Handling	Mean concentration (ppm)	Coefficient of variation (%)
Before	799^b	12.61^a
After	767^a	15.94^b

[1] Values are means of 14 observations.

[2] Means with the same letter within a column are not significantly different ($P<0.05$).

into the premix and the sampling procedure earlier described.

The liquid binders seemed to perform similarly in reducing segregation of iodine (Table 29). Four percent additions of a liquid binder appeared to provide an improvement of premix uniformity determined on the basis of iodine distribution in the material compared to the lower inclusion rate (Table 30).

The fact that handling did not significantly affect segregation of the premix treated with the binder (Table 31) can be explained, to some extent, by the inconsistent coefficients of variation obtained for the replications of the same treatment, i.e. by the nonreproductive nature of the mixing operation itself as stated by Hastings (1961).

The effect of the three variables tested in this project on iodine distribution, i.e. premix uniformity are illustrated in Figure 10.

TABLE 29 Iodine Distribution in the Swine Premix as Affected by Type of the Liquid Binder (Two-Way Analysis)[1]

Type	Mean concentration (ppm)	Coefficient of variation (%)
Soybean oil	788	14.00
Mineral oil	799	13.47
White grease	786	14.63

[1] Values are means of 8 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 30 Iodine Distribution in the Swine Premix as Affected by Level of the Liquid Binder (Two-Way Analysis)[1]

Level (%)	Mean concentration (ppm)	Coefficient of variation (%)
2	756	14.53
4	826	13.53

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 31 Iodine Distribution in the Swine Premix as Affected by Handling (Two-Way Analysis)[1]

Handling	Mean concentration (ppm)	Coefficient of variation (%)
Before	806	12.55
After	777	15.52

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

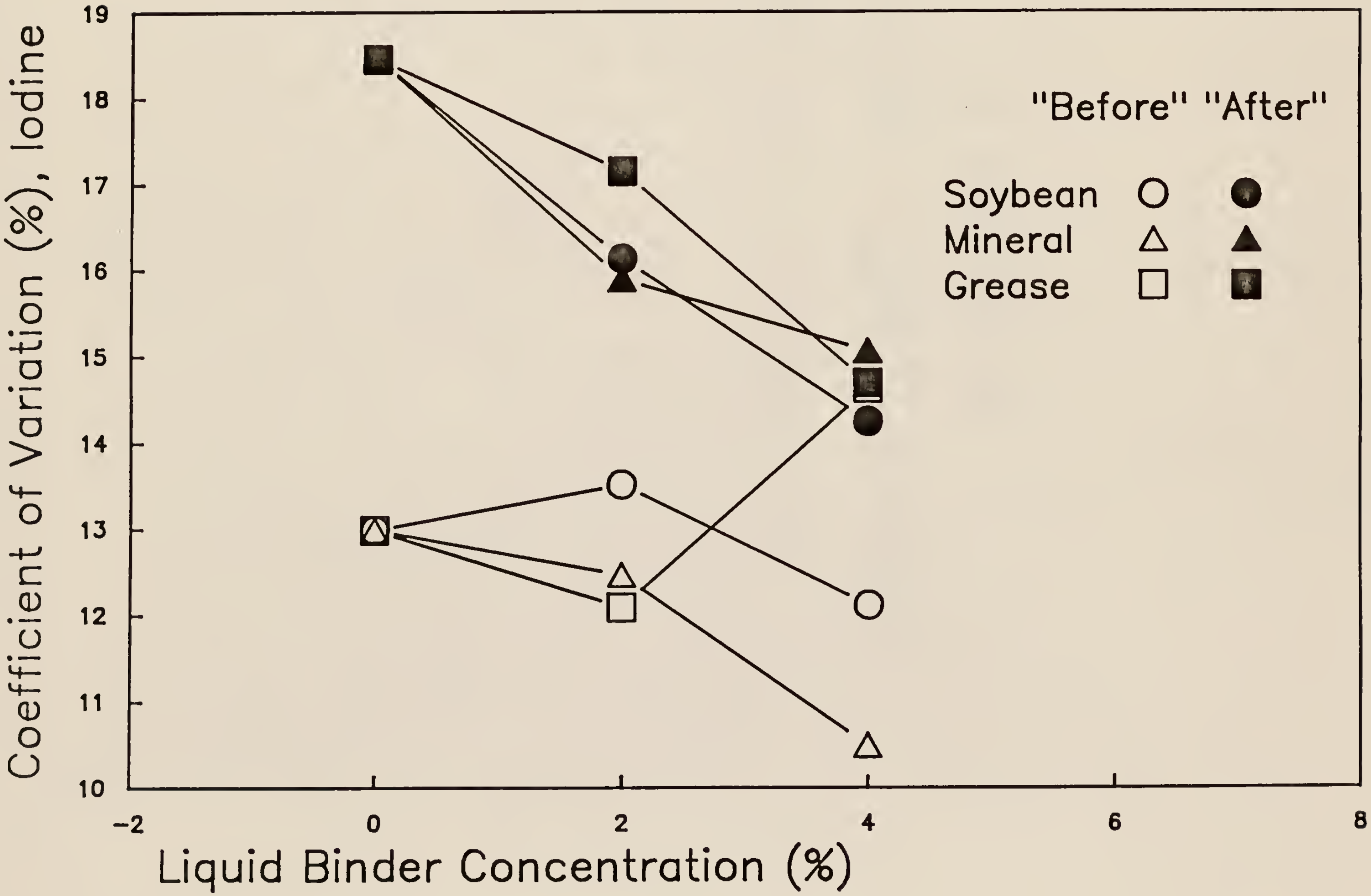

FIGURE 10 Uniformity of Iodine Distribution as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

Dustiness

Results for the drop-test analysis of the premix dustiness are given in Table 32. Rather inconsistent results were obtained, probably, due to the complexity of the mixture and the nonreproducibility of the mixing operation and sampling. Ranges of the dust concentrations (Figure 11) are somewhat indicative on the uniformity of the premix which is in accordance with the results previously discussed. Lower dustiness of the control after it was passed through the conveying equipment than after it was discharged from the mixer (Figure 12) could be attributed to some remixing in the conveying line. However, the batches treated with liquid binders did not show the same trend. In fact, the dustiness of this material after it was subjected to handling slightly increased over "before" which indicated that only a small fraction of fine dust particles became loosened from the agglomerates by the action of handling.

Dustiness of the premix was not significantly affected by the treatments (Table 33); although, a slight decrease of the dust content and a slight uniformity increase of the material treated with liquid binders over the control was evident. As previously stated, the handling equipment did not change the overall dust content of the premix from the

TABLE 32 Premix Dustiness Assays (10 samples per treatment)

Treatment	Replication 1			Replication 2		
	Mean dust. (%)	Range (%)	CV (%)	Mean dust. (%)	Range (%)	CV (%)
Before handling						
Control	8.43	6.71-11.58	16.06	11.59	9.76-14.13	12.16
Soybean oil						
2%	8.95	5.80-11.49	18.08	8.31	7.03- 9.78	9.95
4%	7.14	6.05- 8.80	11.78	8.91	6.81-10.04	10.00
Mineral oil						
2%	7.02	6.18- 8.12	10.07	9.71	8.31-11.61	10.21
4%	7.34	6.36- 8.70	10.03	9.21	7.28-11.14	12.47
White grease						
2%	6.40	5.79- 7.00	5.89	7.75	6.54- 8.97	8.89
4%	6.74	5.75- 7.58	9.10	7.90	6.64- 8.59	7.78
After Handling						
Control	7.71	6.32- 8.96	11.02	10.57	6.62-13.94	18.97
Soybean oil						
2%	8.37	6.26-10.03	15.94	9.24	7.76-10.50	10.67
4%	7.28	5.90- 8.45	9.69	9.43	8.38-10.31	6.32
Mineral oil						
2%	7.38	6.25- 8.06	8.39	10.24	8.42-12.52	11.88
4%	6.78	5.97- 8.65	12.65	9.51	7.60-12.07	14.43
White grease						
2%	6.60	5.71- 7.62	8.96	7.63	6.15- 9.27	12.58
4%	7.16	6.53- 9.03	10.50	7.74	6.88- 8.42	7.82

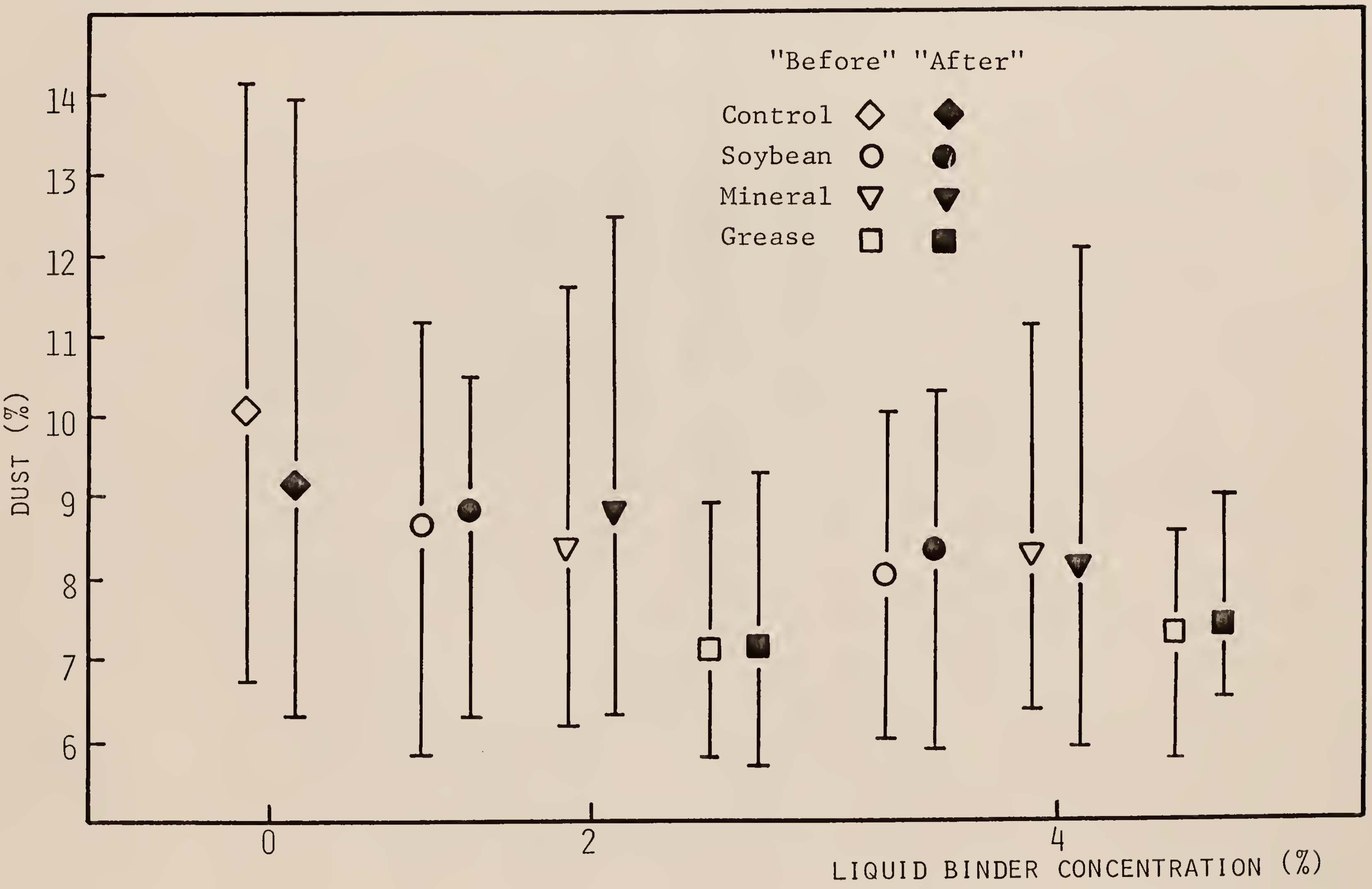

FIGURE 11 Ranges and Means of Dust Concentrations as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

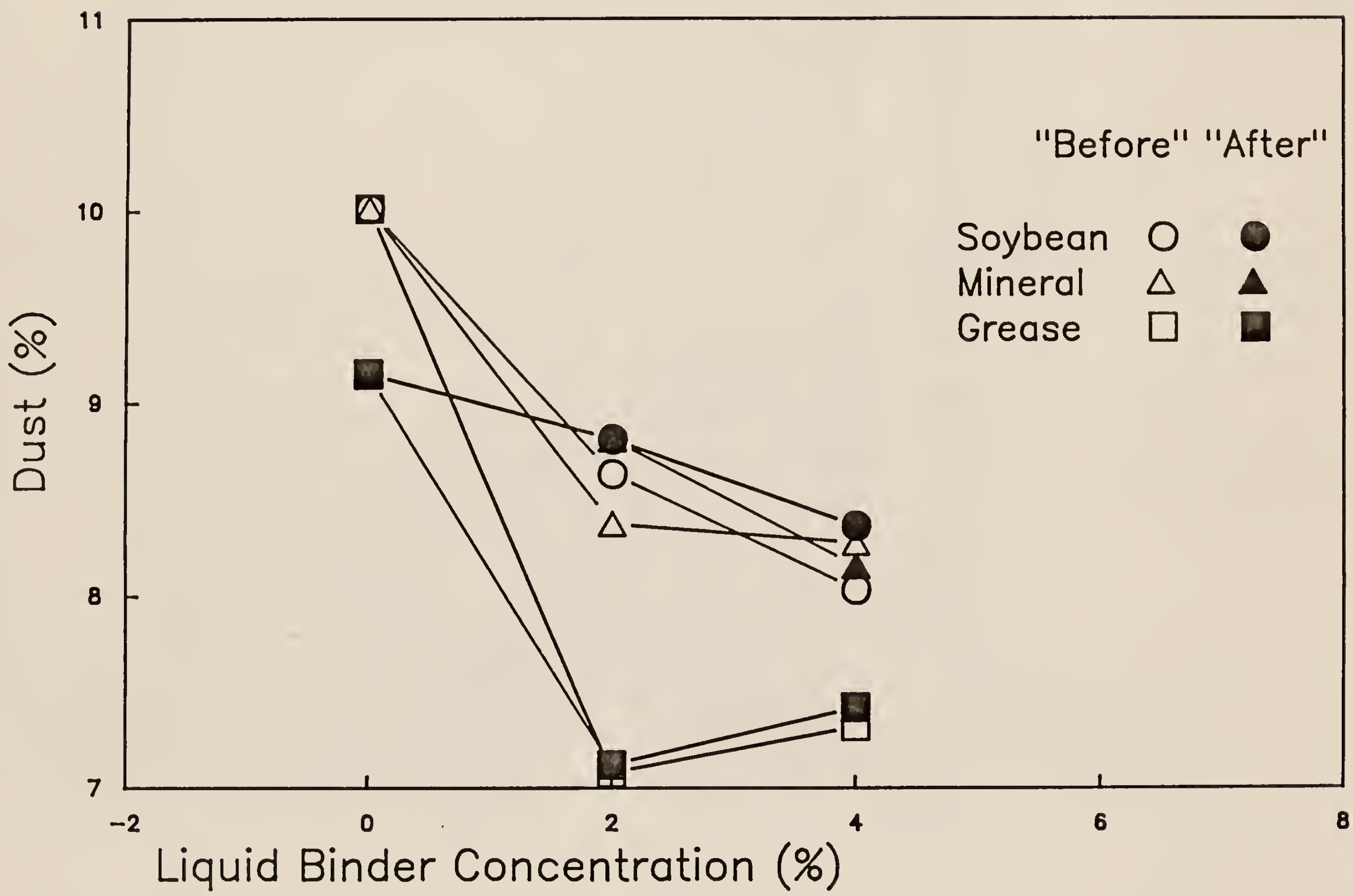

FIGURE 12 Mean Dust Concentration as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

TABLE 33 Dustiness of the Swine Premix as Affected by Treatments (One-Way Analysis)[1]

Treatment	Mean concentration (%)	Coefficient of variation (%)
Control	9.58	14.55
Soybean oil		
2%	8.72	13.66
4%	8.19	9.45
Mineral oil		
2%	8.59	10.14
4%	8.21	12.40
White grease		
2%	7.10	9.08
4%	7.38	8.80

[1] Values are means of 4 observations. Means within a column are not significantly different ($P<0.05$).

mixer, but it caused some segregation of the fine dust particles (Table 34).

The effects of soybean oil and mineral oil seemed to be almost identical on dust suppression and the uniformity of the premix (Table 35). Both of them reduced premix dustiness to around 89% of the control. White grease, on the other hand, provided approximately a 24% dust reduction of the control which was in the range of results obtained by Heber et al. (1986). An increase of the liquid binder inclusion rate from 2 to 4% showed a tendency to decrease the premix dust content and improved the uniformity of the material (Table 36); whereas, (a) white grease did not seem to suppress dust further when its content in the premix was increased (saturation point) (Figure 12), but it did seem to improve the uniformity of the finished premix (Figure 13); (b) mineral oil seemed to behave conversely to the white grease.

The handling effects on the premix batches treated with liquid binders were not significant; although, trends toward increased dustiness and nonuniformity were evident (Table 37).

TABLE 34 Dustiness of the Swine Premix as Affected by Handling (One-Way Analysis)[1]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	8.24	10.89
After	8.26	11.42

[1] Values are means of 14 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 35 Dustiness of the Swine Premix as Affected by Type of the Liquid Binder (Two-Way Analysis)[1]

Type	Mean concentration (%)	Coefficient of variation (%)
Soybean oil	8.45	11.55
Mineral oil	8.40	11.27
White grease	7.24	8.94

[1] Values are means of 8 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 36 Dustiness of the Swine Premix as Affected by Level of the Liquid Binder (Two-Way Analysis)[1]

Level (%)	Mean concentration (%)	Coefficient of variation (%)
2	8.13	10.96
4	7.93	10.21

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

TABLE 37 Dustiness of the Swine Premix as Affected by Handling (Two-Way Analysis)[1]

Handling	Mean concentration (%)	Coefficient of variation (%)
Before	7.95	10.35
After	8.11	10.82

[1] Values are means of 12 observations. Means within a column are not significantly different ($P<0.05$).

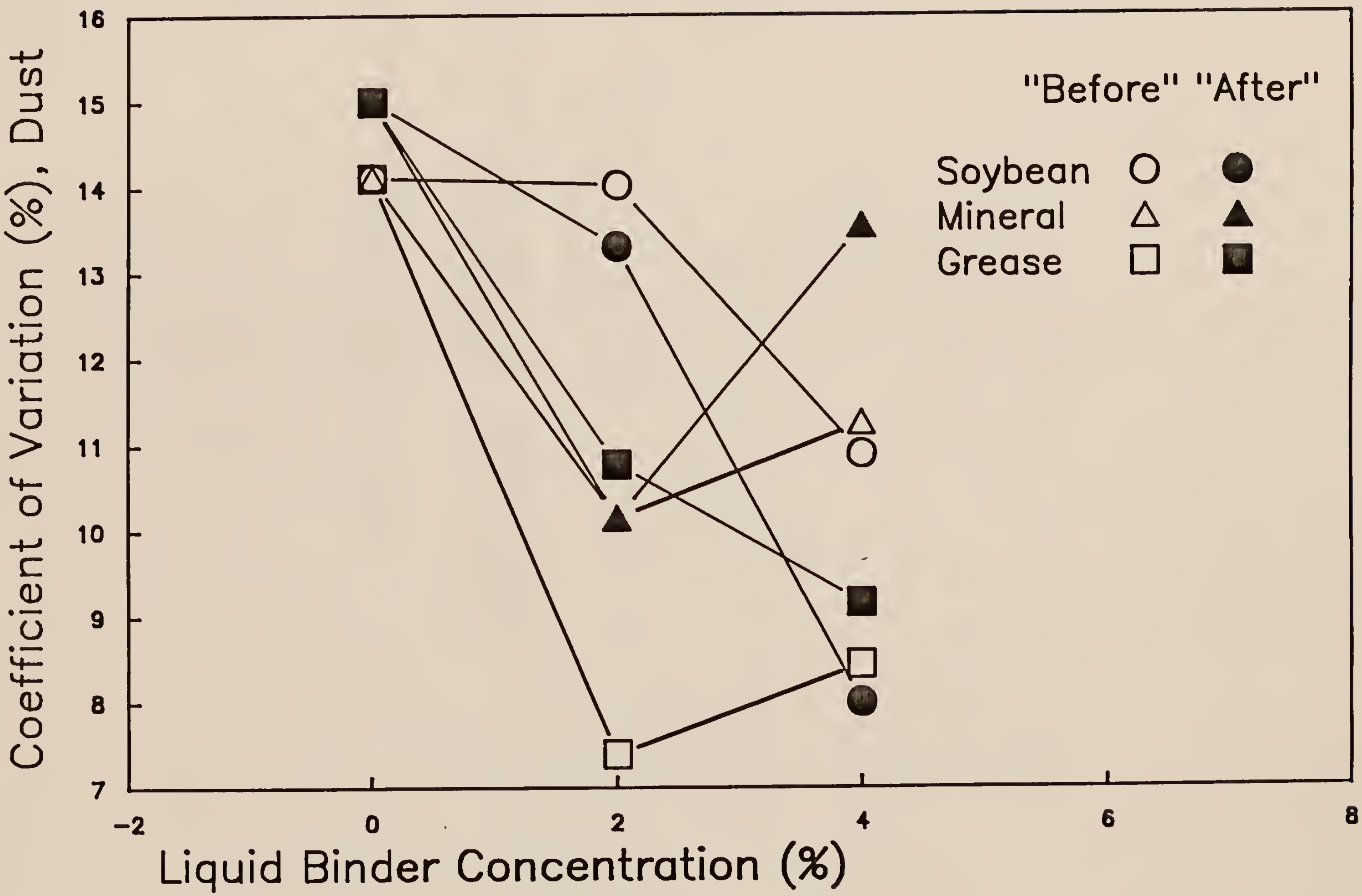

FIGURE 13 Uniformity of Dust Distribution as Affected by Liquid Binder Type, Liquid Binder Level, and Handling.

SUMMARY AND CONCLUSIONS

The effects of a liquid binder addition on reduction of segregation and dustiness in a swine premix were studied before and after the material was handled through conveying equipment.

Three types of liquid binders: soybean oil, mineral oil, and white choice grease at 2 and 4% inclusion rates were tested along with a control which contained no liquid binder. The conveying equipment consisted of a bucket elevator, a screw conveyor, and a bin. Uniformity of the premix was determined by assay procedures for the selected tracers: selenium by magnetic retrieval of iron particles coated with a selenium compound, chlorides by micro titration, niacin by high pressure liquid chromatography (HPLC), and iodine by neutron activation analysis (NAA). Dustiness of the premix was measured by a drop-test under laboratory conditions.

Application of liquid binders was advantageous over the control in terms of improved uniformity of the premix. Mineral oil tended to have the poorest performance and white choice grease the best in retarding segregation of the premix as a consequence of different viscosities. Viscosity appears to be the most important factor when selecting a binder as an agent to reduce segregation. The premix uniformity tended to improve as the level of liquid binders was increased; although, saturation points were observed, in some instances, when further increase of the binder content was not reflected through improved premix quality.

Handling equipment caused significant segregation of ingredients; however, the effects were alleviated, to some extent, by the incorporation of liquid binders into the premix.

Among the tracers selected and assay procedures used, Microtracer^{TM} appeared to be the best choice to profile for uniformity for the consistency of the obtained results, comparability of results with the results from the other methods used, and the simplicity and speed of the procedure.

Performance of the liquid binders in reduction of premix dustiness was similar to the results obtained for segregation: white choice grease reduced dustiness by 24%, and soybean oil and mineral oil by 11% compared to the control.

On the basis of the results obtained in this research, application of liquid binders to premixes can be recommended. However, each particular situation, as a factor of premix formulation and equipment involved, will require special consideration and balancing between gained quality improvement and costs.

APPENDIX A

Particle Size Analysis

Particle size analysis is a test procedure for determining the geometric mean diameter and geometric standard deviation of feed ingredients and feeds (Pfost and Headley, 1976; Anon., 1986). The procedure is based on the assumptions that the material follows a log-normal distribution and that the particles have spherical or cubical shapes.

A set of Tyler[1] woven-wire cloth 203 mm diameter sieves (Table 38) was used. Hundred gram samples were weighed on a Mettler PE 6000 balance with 0.1 g resolution and placed on the top sieve. A Tyler Ro-Tap Sieve Shaker Model B sifted the samples for ten minutes. The weight of the sample retained on each sieve was recorded and used to calculate the following values:

$$d_{gw} = \log^{-1} [\sum (W_i \log d_i) / \sum W_i]$$

$$S_{gw} = \log^{-1} [\sum W_i (\log d_i - \log d_{gw})^2 / \sum W_i]^{0.5}$$

$$A = \beta_s / \beta_v \rho^{-1} e^{(0.5 \ln^2 S_{gw} - \ln d_{gw})}$$

$$N = 1/\beta_v \rho^{-1} e^{(4.5 \ln^2 S_{gw} - 3 \ln d_{gw})}$$

---

[1] W. S Tyler Incorporated, Combustion Engineering, Inc., Mentor, Ohio

where:

d_{gw} - geometric mean diameter by weight distribution of sample

W_i - weight fraction on i'th sieve

d_i - geometric mean diameter of particles on i'th sieve, $d_i = (d_i \times d_{i+1})^{0.5}$

d_{i+1} - diameter of openings in next larger than the i'th sieve

S_{gw} - geometric standard deviation of sample estimate by weight distribution

A - total surface area of particles (cm^2/g)

β_s - shape factor for calculating surface area of particles

β_v - shape factor for calculating volume of particles

ρ - specific weight of material (g/cm^3)

N - number of particles per gram.

It was assumed that the particles were spherical thus, $\beta_s = \pi$, and $\beta_v = \pi/6$. Specific weight of materials (Table 39) was determined by Beckman[R] Air Comparison Pycnometer, Model 930.

TABLE 38 Specification of Sieves Used for Particle Size Analysis

Tyler sieve number	Nominal opening size (μm)
14	1190
20	840
28	590
35	420
48	297
65	210
100	149
150	105
200	74
270	53
325	43
400	38
Pan	--

TABLE 39 Specific Weight of Ingredients, Swine Premix, and Dust

	Specific weight (g cm^{-3})
Ingredients	
Rice hulls	1.42
Calcium carbonate	2.72
Microtracer^{TM}	7.37
Choline chloride	1.21
Niacin	1.44
EDDI	2.61
Swine premix	
Control	1.83
With 4% soybean oil	1.80
With 2% mineral oil	1.79
With 4% mineral oil	1.76
Dust	
Control	1.80
With 4% soybean oil	1.70
With 2% mineral oil	1.74
With 4% mineral oil	1.68

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THE EFFECTS OF LIQUID BINDERS ON REDUCTION OF PREMIX SEGREGATION AND DUSTINESS

by

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The objective of this research was to evaluate the effects of liquid binders on premix segregation and dustiness using mineral oil, soybean oil, and white choice grease at 2% and 4% by weight. Swine premix with no liquid binder was the control. The premix was blended in a horizontal ribbon mixer, elevated by a bucket elevator, conveyed by a screw conveyor, then dropped into a bin. Samples were taken after mixing and after handling. Premix segregation was determined by measuring the distribution of selected tracers: selenium by magnetic retrieval of iron particles coated with a selenium compound, chlorides by micro titration, niacin by high pressure liquid chromatography (HPLC), and iodine by neutron activation analysis (NAA). Dustiness of the premix was measured by a drop-test under laboratory conditions. The premix uniformity was improved by the addition of liquid binders. Mineral oil tended to have the poorest performance and white grease the best in retarding segregation of the premix. Improvement was also obtained as the level of liquid binders was increased; although, saturation points were observed when further increase of the binder content was not reflected through improved premix quality. Handling equipment caused significant segregation of ingredients; however, the effects were alleviated, to some extent, by the incorporation of liquid binders into the premix. Among the tracers selected and assay procedures used, the magnetic retrieval method appeared to be the best choice in profiling for uniformity

for the consistency of the obtained results, comparability of results with the results from the other methods used, and the simplicity and speed of the procedure. White choice grease reduced premix dustiness by 24%, and soybean oil and mineral oil by 11% compared to the control.