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by

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ABSTRACT

Poisoning of North American waterfowl resulting from the ingestion of lead shot by ducks, geese, and swans causes an estimated annual mortality of 2 to 3% of the population (Bellrose 1959). To alleviate this problem the search for a suitable substitute for lead has been underway since the early 1950's.

Proposed substitutes for lead shot were evaluated in a series of acute toxicity tests with pen-reared mallards (Anas platyrhynchos). Most candidate materials were as toxic to ducks as commercial lead shot. Coating or alloying lead with other metals only delayed mortality among dosed ducks. The reputedly "disintegrable" lead shot with the water-soluble binder and the lead containing biochemical additives were also as toxic to mallards as the commercial lead shot.

Mortality was not significantly different among lead-dosed adult or first-year hen and drake pen-reared mallards; lead-dosed adult, wild mallards of both sexes; and lead-dosed adult, male black ducks (Anas rubripes).

The ingestion of one lead shot, size 4, by each of 80 pen-reared mallards caused an average 19% mortality.

The presence and type of grit in the gizzard had a measurable effect on erosion of ingested shot and on shot retention among dosed mallards. Significantly fewer lead-dosed ducks died when fed crushed oystershell grit than when fed either quartz grit or no grit.

INTRODUCTION

The recurring incidence of lead poisoning among North American waterfowl has been a long-standing problem. A precise estimate of the annual mortality caused by lead poisoning among waterfowl is not available, but losses are known to be serious (Bellrose 1959).

Wetmore (1919), Green and Dowdell (1936), Jordan (1952), Jordan and Bellrose (1950), and Bellrose (1951) have studied various aspects of lead poisoning. Bellrose (1959) conducted a thorough review of the literature concerning lead poisoning in waterfowl and concluded that a solution hinged on the development of a non-toxic substitute. Irby et al. (1967) and Grandy et al. (1968) reported on the toxicity of several substitute shot types to mallards.

In the fall of 1966, the ammunition industry's trade organization, The Sporting Arms and Ammunition Manufacturers' Institute (SAAMI), initiated a $100,000 contract with a private research organization, The Illinois Institute of Technology--Research Institute (IIT-RI), to develop a non-toxic shot for waterfowl hunting. The Bureau of Sport Fisheries and Wildlife assumed the responsibility of evaluating the toxicities of the proposed substitutes which might emerge from IIT-RI's efforts.

This report summarizes the toxicological findings concerning the proposed substitutes developed through the IIT-RI - SAAMI contract and some that came from other sources. Also included are the results of additional research on the response of waterfowl to commercial lead shot. These latter studies were designed to clarify questions relating to lead poisoning of waterfowl and to expand on the earlier studies.

METHODS

Toxicities of proposed lead shot substitutes were evaluated by comparing the mortality among ducks dosed with eight substitute shot to the mortality among ducks dosed with a standard dose of eight, size 6 (1 g), commercial lead shot. Certain shot were neither uniform nor strictly comparable in size to that of the lead standard. Thus, the degree of toxicity may have been affected because differences in the surface area of the shot may have influenced shot erosion rates. However, it was thought that these discrepancies would not be critical in the evaluation of the shot types.

Ducks were kept in wire pens, 4.5 x 9.1 x 1.8 m high. The pen bottoms were covered with washed gravel. Each pen was provided with a 0.95-m^3 fiber glass water trough, 3.7 x 0.8 m and 25.4 cm deep, buried flush with the ground and equipped with a 22.9-cm standpipe drain. Well water was supplied from frost-free hydrants. Electric, stock tank de-icers were used to keep troughs ice free. Masonite strips, 0.46 m tall, placed between pens lessened disturbance among ducks in adjacent pens. The test diet was whole-kernel yellow corn offered *ad libitum* in covered, metal poultry feeders. The required quantities of substitute shot (usually eight, size 6) were placed in the duck's gizzard by means of a funnel attached to a small plastic hose. In most toxicity tests, 15 or 20 pen-reared mallards, separated into 5-bird groups, were dosed with the proposed substitute shot or standard lead. Both sexes and either first-year or adult birds were used at random since there appears to be no differential susceptibility (see sex and age comparisons later in this report). Undosed control ducks were maintained for each test.

Tests were conducted in 1967-69 during late fall through early spring, the time of year when most wild waterfowl are exposed to lead and die from lead poisoning.

The length of the tests was arbitrarily set at 40 days; but as long as a test duck retained some shot, the test was extended until the duck died or the shot was expelled. Shot retention was monitored on a weekly basis by fluoroscopic examination of each test duck. Detailed records were maintained on the degree of shot erosion and the number of shot retained. Fluoroscopic records were invaluable in interpreting mortality data since duck mortality is influenced by the duration of retention of shot in the gizzard.

In most tests, ducks were necropsied and histopathological examination was made of kidney tissues for the presence of acid-fast intranuclear inclusion bodies (Locke et al. 1966). The presence of these acid-fast bodies is diagnostic of exposure to lead.

Statistical evaluations of the differential mortalities were made with the Fisher exact probability test (McGuire et al. 1967). Analysis of variance was used to test significance between the mean differences in the number of shot retained.

Types of Substitute Shot

The development of a substitute shot to replace lead shot has followed several approaches. One was to seek a material resistant enough to withstand the chemical and physical erosion in a duck's gizzard, and to use this resistant material as a protective coating on lead shot. A second approach was to alloy other metals with lead to render it less toxic. These approaches were based on the premise that if erosion of lead in the gizzard could be prevented, no particulate lead would be available for absorption, thereby averting lead poisoning. Furthermore, the probability of expelling the shot from the gastrointestinal tract would be enhanced since the gizzard would retain its normal function.

A third thought was to develop a shot that would disintegrate when immersed in water, thus making it unavailable for ducks to ingest.

The fourth approach, considered the most promising by the SAAMI and IIT-Research Institute, was a process known as chelation. In this chemical process, certain organic materials called chelating agents combine with certain heavy metals to form a heterocyclic ring, or chelating ring. It was considered theoretically possible to combine powdered lead with a chelating agent, extrude the material thus formed into wire, form the shot, and thereby produce a type of shot in which the lead would be rendered unabsorbable even though ingested by waterfowl.

Sources of the substitute shot types are listed in Table 1.

Toxicity of Substitute Shot to Mallards

Lead Shot with Nickel Coatings

Lead shot coated with four different thicknesses of nickel were tested for toxicity to mallards. Percentage by weight of nickel in each and thickness of the nickel coating were as follows: 5.5%, 0.0033 cm; 11.0%, 0.0063 cm; 25.0%, 0.0139 cm; and 39.0%, 0.0251 cm.

Although the mortality (100%) caused by shot containing 5.5% nickel equalled that of the standard, the average number of days until death was greater (Table 2). The delay in mortality suggests that the thin nickel coating temporarily prevented exposure of the lead to the ducks. The 11.0% nickel coating significantly ($P<0.05$) decreased mortality within the 40-day test period (Table 3), and the 25.0 and 39.0% coatings extended mortality beyond 40 days.

Forty days after dosing, half of the ducks that had retained shot on either the 25.0 or 39.0% nickel-coated lead were sacrificed to recover and examine the shot, and the remaining ducks from each of the two groups were continued on test. Mortality among the ducks held after 40 days indicated that although the thick coating of nickel delays mortality, ducks will eventually die if they retain shot. Among the ducks dosed with either 25.0 or 39.0% nickel-coated lead shot, fluoroscoping at 40 days showed that 20 of 30 ducks had retained at least one shot in the gizzard. Mortality from lead poisoning might have been even higher if all ducks which retained shot had been held beyond 40 days. The total mortality among ducks dosed with lead shot containing the thicker coatings of nickel (25.0 or 39.0 vs. 5.5 or 11.0%) would be less because the delay in exposure to lead would enhance the possibility of expelling shot.

Lead-Phosphor Tin Alloy Shot

A patent for the production of a lead-phosphor tin shot claimed that it was non-toxic to waterfowl when ingested by wild ducks; however, Jordan and Bellrose (1950) found that a dose of six, size 6, shot caused 80% mortality among 10 domestic mallards within 22 days.

In our tests, lead-phosphor tin alloy (also containing some arsenic and antimony) was as toxic to mallards as the lead standard (100% mortality; Table 2). On the basis of the average number of days until death, this alloy was slightly more toxic (14 days until death) than the lead standard (18 days until death; Table 2).

Lead Shot with Tin-Nickel Alloy Coatings

Mortality caused by lead shot coated with thin strikes of nickel followed by two different thicknesses of a tin-nickel alloy (0.0041 or 0.0167 cm of alloy) equalled that of the lead standard (80%; Table 4). In addition to the lead standard, ducks were dosed with nickel-coated lead shot (5.5% nickel by weight) for a second standard because we thought that a more meaningful comparison between the relative resistance of the tin-nickel coatings would be obtained if they were compared to the similarly resistant (5.5%) nickel-plated lead shot. In this test, the tin-nickel alloy coating apparently was more resistant to erosion than the 5.5% nickel-coating since the ducks dosed with the tin-nickel alloy lived longer than those dosed with nickel plated shot; however, this may simply reflect the thicknesses of the coatings (Table 4).

Steel Shot with Lead Coatings

Coating steel shot with lead was designed to increase the weight of the shot and to provide a surface ballistically similar to a standard lead pellet. By using minute amounts of lead for the coatings, it was thought that ducks would be able to excrete the small amounts of lead, thus preventing lead poisoning.

The shot with the thinner of the two coatings (0.056 vs. 0.092 g lead) was significantly ($P<0.01$) less toxic (60% mortality) than the lead standard (100% mortality; Table 5). The ducks that survived shot with the thinner coating were able to erode and excrete the small quantities of lead from coatings although most ducks exhibited typical symptoms of lead poisoning soon after dosing. Fluoroscopic examination of the ducks which recovered revealed that the shot they had retained in their gizzards were completely free of the lead coating.

Lead-Tin Alloys

Two lead-tin alloys (Code 3 and Code 7 in Table 6) were evaluated for toxicity to mallards. The Code 3 alloy contained 76% lead, 7% tin, and 17% antimony; and the Code 7 alloy contained 50% lead and 50% tin. Although these alloys were in irregular size pieces, the dose offered contained pieces of alloy that equalled the weight of eight, size 6, commercial lead shot (1.0 g). Mortality from the Code 3 alloy (75%) was significantly less ($P<0.05$) than the mortality from the lead standard (100%). The average number of days till death was 21 for the Code 3 alloy compared with 10 for the lead standard. All alloy-dosed survivors voided most of their alloy pieces soon after dosing, usually within 2 weeks. Early voidance increased the probability of survival. The decreased amount of lead in the alloy may have contributed to voidance by allowing normal gizzard function for a longer period. Duck mortality from the Code 7 alloy was significantly less ($P<0.01$) than that of the standard (20 vs. 100%) and the average number of days till death was 30. The alloying process and the decreased amount of lead in the alloys apparently caused the reduction in mortality. However, many ducks voided alloy pieces soon after dosing, which also would contribute to decreased mortality.

Disintegrable Lead Shot (with Water-Soluble Binder)

Two different pellet types, described as water-soluble lead shot (Type A and Type B, Table 7), were evaluated.

The efficacy of the water-soluble shot in preventing lead poisoning in mallards was minimal. The mortality caused by the disintegrable shot (73% for each type) was not significantly different ($P<0.05$) and only slightly less than the mortality resulting from the standard dose (87%). Deaths, on the average, occurred sooner among the ducks dosed with the disintegrable shot. This probably occurred because shot was reduced to fine powder after 24 hours in the gizzard, thus increasing the amount of soluble lead available compared with that from the standard lead pellets.

Other workers have tested lead-magnesium shot which alledgedly disintegrated in water (Green and Dowdell 1936; Irby et al. 1967). A lead-magnesium alloy containing 2.4% magnesium broke open or "flowered" in water yet caused mortalities ranging from 56 to 63% when ingested by pen-reared mallards (Irby et al. 1967).

So-called disintegrating shot types that we tested did not disintegrate. Shot Types A and B that we immersed in tap water and vigorously agitated weekly for 3 months remained essentially intact.

The use of a disintegrating shot may be inadvisable since a recent study has shown that particulate lead in marshes may be hazardous to waterfowl. In simulated marshes, Irwin and Karstad (1972) found that mallards exposed to 89.0 g/m^2 particulate lead suffered a 57% mortality. Birds exposed to 178 g/m^2 suffered 100% mortality. Some mortality (17%) occurred when birds were exposed to only 17.8 g/m^2 of particulate lead. The degree of mortality recorded in their study may be biased downward because commercial duck pellets were fed during 2 weeks of the study. Commercial duck pellets are known to have a mollifying effect on the toxic properties of lead shot (Andrews et al., unpublished data, Patuxent Wildlife Research Center).

Lead with Biochemical Additives

One of the approaches pursued by the IIT-RI for developing a non-toxic shot was to seek biochemical additives which, when combined with lead, would prevent or diminish the release of lead ions. Many additives were screened in IIT-RI laboratory tests. Creatinine, an amino acid, and ethylene diamine tetra-acetic acid (EDTA), a chelating agent, were the most promising. Each additive was combined at levels of 1 and 2% with lead powder and the mixture extruded in wire form. The resulting wire, however, was too brittle for shot fabrication, and further work was curtailed. Nevertheless, samples of the wires were obtained for toxicity testing. Pieces of wire, each approximately the weight of one, size 4, buckshot (1.4 g) were used to dose mallards. One, size 4, buckshot was used as the lead standard in this test.

Mortality of 75 to 90% among ducks dosed with the pieces of wire containing biochemical additives exceeded the mortality (70%) for the lead standard (Table 8). Among the lead standards, shot voidance after dosing lowered the mortality below that usually encountered with eight, size 6, lead shot (approximately 90%).

Acid-fast intranuclear inclusion bodies were present in kidneys of all 35 ducks examined from the creatinine group and in 31 of 32 kidneys of ducks from the EDTA group. The presence of these characteristic inclusion bodies gives further evidence of the inability of the chelating agents to prevent lead absorption.

Further Studies of the Effects of Lead Shot on Waterfowl

Toxicity of Lead Shot among Sex and Age Categories of Pen-Reared Mallards

Jordan and Bellrose (1950) stated that mature ducks were more susceptible to lead poisoning than were 9-week-old juveniles. These authors later (1951) reported that, at least seasonally, hen susceptibility exceeded drake susceptibility to lead poisoning.

Since lead poisoning losses usually occur on wintering grounds in fall and early spring when ducks are fully fledged, a test was designed to compare mortality rates of first-year and adult pen-reared mallards. Results revealed that mortality did not significantly differ according to sex or age when mallards were dosed with eight, size 6, lead shot. Mortality varied from 90 to 100% (Table 9). Weekly fluoroscopic examinations showed that four of the five ducks that survived had voided all shot within 2 weeks.

Toxicity of Lead Shot among Pen-Reared Mallards, Black Ducks, and Wild Mallards

In all tests comparing the relative toxicities of proposed substitute materials with that of commercial lead shot, we used pen-reared mallards, a standard dose of eight, size 6, shot (1 g), and a diet of whole-kernel yellow corn. With this combination, mortality ranged from 80 to 100%. However, there remained the possibility that pen-reared mallards were less susceptible to lead poisoning than wild mallards or the closely related black duck. Experimental studies by Jordan and Bellrose (1951) indicated that captive wild mallards were more susceptible to lead poisoning than mallards from pen-reared stock.

Through the courtesy of Frank C. Bellrose, we received a shipment of wild hen and drake mallards from Illinois in February 1968. Some ducks died during a delay enroute. The survivors were held in test pens for 2 weeks before dosing. Groups of these wild drake and hen mallards, pen-reared drake and hen mallards, and pen-reared drake black ducks were dosed at the same time.

The results indicated that wild mallards, pen-reared mallards, and pen-reared black ducks were equally susceptible to lead poisoning at the dosage level used. Mortality was 100% for all dosed groups except the drake pen-reared mallards which had 95% mortality (Table 10). Four control ducks in this test, two wild mallards and two drake black ducks, died from causes unrelated to lead poisoning. These control wild mallards were the poorest of the lot and stress factors related to their austere diet of whole corn and the long-distance shipment may have caused their death. These findings, which contrast with those of Bellrose, could have been caused by different shot retention rates. Our birds retained most of their shot whereas data were unavailable for Bellrose's tests. A difference in shot retention could appreciably affect the mortality rate of his mallards.

Toxicity of One Lead Shot, Size 4, among Mallards

Jordan and Bellrose (1950) showed that the ingestion of a single lead pellet, size 6, would kill 60-80% of a group of captive wild mallard drakes. In addition, an examination of over 18,000 duck gizzards collected from hunters in many parts of the United States showed that of those gizzards containing shot, one-third contained only one pellet (Jordan and Bellrose 1951).

When we dosed 80 adult mallards (40 hens and 40 drakes with one, size 4, lead shot, 19% died within an average of 20 days (Table 11). Bellrose (1959) stated that "In a population of wild mallard drakes, a population made up equally of adults and juveniles, one No. 6 pellet per bird is estimated to cause an increase in mortality rate of about 9 per cent, two pellets per bird an increase of about 23 per cent, four pellets per bird an increase of about 36 per cent, and six pellets per bird an increase of about 50 per cent." Differences in mortality may be related to the rate of shot voidance. Duck survival in our tests was closely related to rapid shot voidance after dosing. Fluoroscopic examination of weekly survivors showed that only 27 of 76 survivors (36%) had retained shot 2 weeks after dosing (Table 12). Many ducks voided their shot before much lead was eroded, but many other ducks apparently completely eroded the shot and were able to survive. Thus, much variation in individual resistance to the toxic effects of lead must exist.

Effects of Grit on Ingested Lead Shot in Mallards

Several authors have mentioned the suspected relationship between grit in the gizzard and lead poisoning in waterfowl (Wetmore 1919; Shillinger and Cottam 1937; Jordan and Bellrose 1951; Jordan 1952; Beer and Stanley 1965; Godin 1967). These reports have been conflicting. Some workers believe that excess grit aids in shot voidance, whereas others state that shot erosion is increased with excessive grit.

Wetmore (1919) stated, "Birds that had the stomach well filled with gravel or that had access to an abundance of gravel were weakened more quickly than those that had been confined for some time where they could not secure grit." The amount of grit was thought to affect the rate of shot erosion. Beer and Stanley (1965), however, stated that excess grit passes rapidly through the birds, taking any (lead) pellets with it.

Jordan (1952) experimentally found that the rate of lead shot erosion was influenced by grit. He gave each of two 5-bird groups of immature tame mallards two, size 6, preweighed lead shot. One group he force-fed 10 pieces of grit (hen size) several days before dosing with lead. The other group was not given grit, but when examined later, all duck gizzards contained 0.2-0.3 cc of sand. He held the birds for 1 week. The erosion rates (g per shot per day) averaged 0.0112 g for the ducks given grit and 0.0089 g for the ducks deprived of grit.

Since duck survival is closely associated with the excretion of the lead pellet or the lead salts, it occurred to us that the effect of grit may be an important variable in the evaluation of relative toxicity of substitute shot to waterfowl. There has been some indication, moreover, that grit types may differ in their effects on lead poisoning (Godin 1967). Grit containing abundant calcium, such as oystershell, has shown some tendency to mollify the toxic effects of ingested lead in mallards.

In the spring of 1967, mallard eggs were collected from a breeding flock and incubated. The ducklings were reared until 5 weeks of age on a concrete floor covered with wood shavings; they were then placed in elevated 1.5- x 2.7-m pens, each supplied with a 0.95-m^3 water tank (Cornwell and Hartung 1963). The ducks were fed commerical duck pellets and mixed grains (wheat, rice, millet, sorghum, and corn), and were deprived of grit.

Thirty-six mallards of both sexes were apportioned four each to nine pens in September 1967. Two grit types (quartz gravel and crushed oyster-shell) were replicated three times and randomly offered to the test birds. The remaining three pens of mallards were deprived grit. All ducks were dosed with eight, size 6, lead shot and fed whole-kernel yellow corn.

All of the ducks without grit died; 75% of the ducks fed quartz grit succumbed; and only 33% of the ducks fed oystershell grit died (Table 13). Mortality among ducks fed oystershell was significantly less than that among ducks fed quartz ($P=0.05$) and those deprived of grit ($P<0.002$). The retention of individual lead pellets was greatest in ducks without grit (Table 14). The mean rate of shot erosion (g per shot per day) of recovered shot from ducks with grit (0.0048 or 0.0052) was more than double that of ducks without grit (0.0021) (Table 15). Kimball and Munir (1971) reported that the erosion rate of a single, size 4, lead shot in a simulated gizzard with a pH of 2.0 was about 0.005 g per day.

The average weight of grit in the gizzard (based on grams of grit recovered at necropsy) was highest for mallards fed quartz (9.3 g, range 2.5-19.0 g). Weight of grit recovered from ducks fed oystershell averaged 1.4 g (range 0.1-2.9 g). Ducks maintained without grit managed to acquire an average of 0.3 g grit from their food and holding pens.

Kidneys from ducks fed quartz and from ducks deprived of grit were all positive for acid-fast intranuclear inclusion bodies. Of the ducks fed oystershell, all survivors and two of the five nonsurvivors were negative for acid-fast bodies.

Interpretation of the shot erosion data necessitates the assumption that the rate of shot erosion is uniform. In actuality, erosion is probably initially rapid but lessens as the duck becomes sicker, causing a decrease in gizzard activity and thereby reducing the physical erosion of the shot. Hanzlik (1923) has shown that crop peristalsis in lead-poisoned pigeons and ducks is increased by the direct stimulation of smooth muscle by lead. This increased activity of the digestive tract would undoubtedly result in greater amounts of lead becoming absorbed sooner.

For comparative purposes, shot erosion rates are calculated on a gram per shot per day basis. Shot retention obviously is closely related to shot erosion in that retention values decrease as shot are completely eroded.

Rapid shot erosion suggests gizzard motility and therefore a high probability of expulsion of shot through the duodenal opening; but the rapid erosion associated with motility also is expected to result in faster dissolution of the lead, thereby causing death sooner. Both of these effects were apparent in our ducks fed quartz. These ducks, compared with ducks without grit, voided more shot (Table 14) and suffered lower but more rapid mortality (Table 13). The digestive fluids of ducks without grit presumably were sufficient to erode enough lead to quickly render the gizzards immotile, impeding further physical erosion and shot voidance. Fluoroscopic records support this contention; very little change in shot size was noted throughout the test period in ducks without grit, and the recovered shot were eroded only slightly (Table 15).

The average hydrogen ion concentration (pH) in the gizzards of Pekin ducks was 2.3 (Farner 1942), which denotes high acidity and indicates that gastric juices alone are capable of chemically eroding lead.

The effect of grit type on mortality is indicated by the difference in shot erosion during the first week. The retained shot were eroded more in ducks fed oystershell than in ducks fed quartz, with shot ranging from half original size to the size of a pencil tip. In ducks fed quartz, shot showed little erosion, and were nearly of the original size at the end of 1 week.

Hanzlik and Presho (1923) reported that calcium sulphide had beneficial therapeutic effects among adult pigeons dosed with lead by diminishing the solubility, and thus the absorption, of lead. Thompsett (1939) found that the absorption of lead from the alimentary tract of mice on a high calcium diet was small and not greatly influenced by the amount of lead administered; he speculated that the influence of the calcium on intestinal acidity might affect the solubility of the lead.

It appears, other conditions being equal, that duck mortality from lead poisoning reflects the effects of grit on shot erosion and shot retention. In ducks with grit, the detrimental effects of rapid availability of particulate lead associated with a rapid rate of shot erosion are somewhat offset by the concomitant chance of voidance of the shot. The net result is less, but more rapid mortality among ducks with grit than in ducks deprived of grit. Oystershell grit seems to reduce the severity of lead poisoning more than did quartz grit. Apparently certain chemical reactions create this difference although the rate of normal flow of food through the gastrointestinal tract seems to be involved as well. Normal passage of food may flush some lead particles from the digestive tract.

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Table 1. Sources of substitute and commercial shot types.

Type	Source
Lead shot with nickel coatings	The International Nickel Co. of Canada, Ltd.
Lead shot with tin-nickel alloy coatings	The International Nickel Co. of Canada, Ltd.
Steel shot with lead coatings	Illinois Institute of Technology-Research Institute
Lead-phosphor tin alloy shot	Remington Arms Co., Inc.
Lead-tin alloys	National Lead Co.
Lead shot, disintegrable (with water-soluble binder)	National Research Council of Canada Industrial Tectonics, Inc.
Lead wire pieces with biochemical additives	Illinois Institute of Technology-Research Institute
Lead shot, commercial	Olin Corporation, Winchester-Western Division

Table 2. Mortality of yearling drake, pen-reared mallards dosed with commercial lead shot, nickel-coated lead shot, and lead-phosphor tin alloy shot.

Shot type	Number of ducks	Deaths in five-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	15	5	5	5	100	18 (7-28)
Lead (8, size 6, shot coated with nickel to avg thickness of 0.0033 cm; 5.5% nickel by wt)	15	5	5	5	100	26 (16-38)
Lead (8, size 7½, shot coated with nickel to avg thickness of 0.0139 cm; 25.0% nickel by wt)	15	3	1	0	67[a]	52 (44-67)
Alloy[b] (96.5% lead, 0.5% arsenic, 3.0% antimony, and 0.3% phosphor tin)	15	5	5	5	100	14 (6-25)
Undosed (controls)	15	0	0	0	0	--

[a] No mortality had occurred at 40 days; but four of six ducks (67%) that had retained shot died after 40 days

[b] Alloy components exceed 100% as stated in the U.S. Patent (#1,900,182) awarded March 7, 1933, to Remington Arms Co., Inc. The above combination of materials is given as a typical non-poisonous shot metal composition in the Patent.

Table 3. Mortality of yearling hen, pen-reared mallards dosed with commercial lead shot or nickel-coated lead shot.

Shot type	Number of ducks	Deaths in five-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	15	5	5	4	93	16 (9-33)
Lead (8, size 7, shot coated with nickel to avg thickness of 0.0063 cm; 11.0% nickel by wt)	15	3	3	2	53[a]	25 (14-38)
Lead (8, size 8, shot coated with nickel to avg thickness of 0.0251 cm; 39.0% nickel by wt)	15	1	1	0	50[b]	43 (42-46)
Undosed (controls)	15	0	0	0	0	--

a/ Difference from lead standard significant (P = 0.018)

b/ No mortality had occurred at 40 days, but two of four ducks (50%) that retained shot died after 40 days

Table 4. Mortality of yearling hen, pen-reared mallards dosed with commercial lead shot, lead shot coated with nickel, and a tin-nickel alloy shot.

Shot type	Number of ducks	Deaths in five-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	15	5	4	3	80	13 (5-31)
Lead (8, size 6, shot coated with nickel to avg thickness of 0.0033 cm; 5.5% nickel by wt)	15	2	4	3	60[a]	11 (8-18)
Lead (8, size 6, shot coated with a strike of Ni [0.00025 cm] followed by tin-nickel alloy to avg thickness of 0.0041 cm)	15	3	5	4	80	18 (5-39)
Lead (8, size 8, shot coated with a strike of Ni [0.00111 cm] followed by tin-nickel alloy to avg thickness of 0.0167 cm)	15	5	5	2	80	26 (7-41)
Undosed (controls)	6[b]	0	0	0	0	--

a/Difference from lead standard non-significant (P<0.123)

b/Drakes

Table 5. Mortality of yearling hen, pen-reared mallards dosed with commercial lead shot and lead-coated steel shot.

Shot types	Number of ducks	Deaths in five-bird replicates 1	2	3	4	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	20	5	5	5	5	100	9 (4-19)
Steel (8 steel shot plated with lead from 0.305 cm to size 4; 0.330 cm diam) (0.056 g lead)	20	3	3	2	4	60[a]	7 (5-16)
Steel (8 steel shot plated with lead from 0.279 cm to size 4; 0.330 cm diam) (0.092 g lead)	20	5	5	5	4	95	7 (4-17)
Undosed (controls)	8	0	0	0	0	0	--

[a] Difference from lead standard significant (P<0.004)

Table 6. Mortality of yearling hen, pen-reared mallards dosed with commercial lead shot and two different lead-tin alloys (eight pieces of alloy approximately size 6 equalling 1.0 g).

Shot or alloy type	Number of ducks	Deaths in five-bird replicates 1	2	3	4	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	20	5	5	5	5	100	10 (6-22)
Code 3 alloy (76% lead, 7% tin, 17% antimony)	20	4	4	4	3	75[a]	21 (7-32)
Code 7 alloy (50% lead, 50% tin)	20	2	1	0	1	20[b]	30 (22-44)
Undosed (controls)	16	0	0	0	0	0	--

[a] Difference from lead standard significant (P<0.024)

[b] Difference from lead standard significant (P<0.004)

Table 7. Mortality of yearling drake, pen-reared mallards dosed with commercial lead shot and disintegrable lead shot.

Shot type	Number of ducks	Deaths in five-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (8, size 6, commercial shot)	15	5	5	3	87	17 (5-48)
Lead (8, size 4, shot formed from lead powder and a mucilage type water-soluble binder, Type A)	15	3	4	4	73[a]	14 (4-49)
Lead (8, size 4, shot formed from lead powder and a 5% [by wt] polyvinyl acetate, water-soluble binder, Type B)	15	4	4	3	73[a]	9 (7-25)
Undosed (controls)	6	0	0	0	0	--

[a]Difference from lead standard non-significant at 0.05 (P>0.195)

Table 8. Mortality of yearling drake, pen-reared mallards dosed with lead wire pieces containing biochemical additives and one, size 4, lead commercial buckshot.

Shot type	Number of ducks	Deaths in five-bird replicates 1	2	3	4	Mortality (%)	Average number of days till death (extremes in parentheses)
Lead (1, size 4, buckshot)	20	2	4	4	4	70	13 (6-25)
Lead (1.4 g wire piece containing 99% lead powder and 1% creatinine)	20	4	5	4	4	85[a]	12 (5-24)
Lead (1.4 g wire piece containing 98% lead powder and 2% creatinine)	20	4	5	4	5	90[a]	12 (5-23)
Lead (1.4 g wire piece containing 99% lead powder and 1% EDTA)	20	3	5	5	5	90[a]	11 (4-25)
Lead (1.4 g wire piece containing 98% lead powder and 2% EDTA)	20	3	5	3	4	75[a]	10 (5-18)
Undosed (controls)	8	0	0	0	0	0	--

[a] Difference from lead standard non-significant at 0.05 (P = 0.118 or less)

Table 9. Mortality of pen-reared mallards of different sex and age dosed with eight, size 6, commercial lead shot.

Sex	Age	Number of ducks	Deaths in five-bird replicates 1	2	3	4	Mortality (%)	Average number of days till death (extremes in parentheses)
Female	Adult	20	4	4	5	5	90[a]	13 (5-26)
	First year	20	5	5	5	5	100[a]	10 (6-22)
Male	Adult	20	5	4	4	5	90[a]	13 (6-34)
	First year	20	5	5	4	5	95[a]	15 (4-29)
Undosed controls (4 ducks of each sex and age)		16	0	0	0	0	0	--

a/ Differences among four sex-age groups non-significant at 0.05 (P>0.115)

Table 10. Mortality of yearling pen-reared mallards and black ducks, and wild mallards dosed with eight, size 6, commercial lead shot.

Duck type	Number of ducks	Deaths in four- or five-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Tame mallard						
Male	15	4	5	5	93	10 (4-21)
Female	15	5	5	5	100	10 (5-23)
Undosed control	6	0	0	0	0	--
Wild mallard						
Male	15	5	5	5	100[a]	11 (8-15)
Female	12	4	4	4	100[a]	11 (7-30)
Undosed control	6	1	1	0	33[b]	--
Black duck						
Male	15	5	5	5	100[a]	9 (4-19)
Undosed control	6	0	1	1	33[b]	--

a/ Difference from lead standard non-significant at 0.05 (P>0.165)
b/ Died from causes other than lead poisoning

Table 11. Mortality of yearling, pen-reared mallards dosed with one, size 4, commercial lead shot.

Sex	Number of ducks	Deaths in ten-bird replicates 1	2	3	4	Mortality (%)	Average number of days till death (extremes in parentheses)
Male	40	1	2	3	1	18	22 (12-40)
Female	40	3	3	2	0	20	18 (9-41)
Undosed controls (4 males; 4 females)	8	0	0	0	0	0	--

Table 12. Weekly survivors and shot incidence among ducks dosed with one, size 4, commercial lead shot.

Ducks[a/]	Weeks after dosing 1		2		3		4	
	No.	%	No.	%	No.	%	No.	%
With shot	60	75	27	36	11	15	1	2
Without shot	20	25	49	64	60	85	65	98

[a/] A total of 80 mallards was dosed

Table 13. Mortality of yearling, lead-dosed (8 shot, size 6) mallards offered two grit types or no grit.

Treatment	Number dosed	Deaths in four-bird replicates 1	2	3	Mortality (%)	Average number of days till death (extremes in parentheses)
Oystershell	12	0	1	3	33[a/][b/]	18 (7-28)
Quartz	12	2	4	3	75[c/]	20 (8-29)
No grit	12	4	4	4	100	23 (7-35)

[a/] An additional duck died from causes other than lead poisoning

[b/] Difference in percentage mortality among birds with no grit or quartz grit significant ($P<0.002$) and ($P = 0.05$), respectively

[c/] Difference from mortality among birds with no grit non-significant at $P = 0.05$ ($P = 0.109$)

Table 14. Average number of shot retained among mallards fed eight, size 6, lead shot and offered two grit types or no grit.

Treatment	Number of ducks	Average number of shot in gizzard after 1 wk	2 wk	3 wk	4 wk	5 wk	Mean number of shot recovered from dead birds	
Oystershell	12	6.6	2.6	1.0	0.1	0.0	1.8	A[a/]
Quartz	12	6.4	4.8	3.3	0.0	0.0	3.5	A
No grit	12	7.5	7.1	7.9	6.7	-	6.4	B

[a/] The different arabic letters denote differences ($P<0.05$) in mean number of shot retained in the gizzard

Table 15. Erosion rates of lead shot recovered from mallards fed eight, size 6, lead shot and offered two grit types or no grit.

Grit type	Number of ducks dosed	Number ducks retaining shot at death	Rate of shot erosion (g per shot per day)[a/]	
			Mean	Range
Oystershell	12	9	0.0052	0.0040-0.0067
Quartz	12	3	0.0048	0.0014-0.0123
No grit	12	12	0.0021	0.008-0.0038

[a/] Erosion rates were based on the average number of grams eroded per shot per day since shot retention rates were variable; individual ducks retained from 0 to 8 of their 8-shot dose

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