#75: FINTRAC- Invironmental Aspects

RCG/Hagler, Bailly, Inc.

INFORMATION EXCHANGE SYNOPSIS:

PUBLIC POLICIES AND INDUSTRIAL TRENDS RESPONDING TO CLEAN AIR LEGISLATION AND THE PRODUCTION POTENTIAL OF THE VERNONIA AND JATROPHA PLANTS

Final Report

Prepared for:

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to the
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Market Development and Investment
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Washington, D.C.

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TABLE OF CONTENTS

APPENDICES

SECTION 1: BACKGROUND

As a result of the demonstrated environmental harm caused by certain compounds in widely-used commercial products (e.g., volatile organic compounds--VOCs--in oil-based paints), public concern regarding their continued utilization is growing. Federal and state governments have responded to this concern by passing legislation to reduce, and in some cases ban, the commercialization of these compounds.

For example, stringent emission control requirements are being formulated for compounds that contribute to ozone formation, such as nitrogen oxides and volatile organic compounds. These regulations are likely to affect a variety of consumer and industrial products. Also, under the Clean Air Act, actions are being taken to bring geographic areas into compliance with national ambient air quality standards. Air quality regulations promulgated through the Act are typically enforced by the states via the State Implementation Plan (SIP). In areas that have not met air standards, major emissions sources are heavily regulated and minor sources (VOCs and diesel fuel) are being considered for regulation by state and local authorities responsible for the implementation of the SIP.

Some of the most harmful of these toxic products apparently have natural, environmentally benign substitutes. Recent information has indicated that such polluting substances as VOCs and diesel fuel have substitutes in the form of extracts from naturally occurring products which are well established in various ecosystems throughout the world.

The U.S. Agency for International Development (AID) has reviewed the preliminary research and environmental data on these naturally occurring products. As a result, it has suggested that two plant varieties, which seem promising as environmentally acceptable substitutes for detrimental substances, be explored. The first is Vernonia, which could be substituted for VOCs, and the second is Jatropha, a potential substitute for diesel fuel.

AID's Africa Bureau, Market Development and Investment (MDI) group is particularly interested in these plants, which are found in abundance in sub-Saharan Africa. The commercial exploitation of these plants could provide much-needed hard currency for the export-deficient, southern African nations.

The MDI group has recognized that in order to develop these plant materials for commercial use, the appropriate sub-Saharan countries will need to attract foreign joint-venture investment to provide the necessary capital for in-country processing and the establishment of a broad-based contract farming infrastructure. Additionally, there is a need to create market outlets for the derived products. Last, before MDI approaches the private sector, it will be necessary to determine the status of existing regulatory policy with regard to VOCs and diesel fuel, and the nature of any prospective legislation which may affect them.

Such public bodies as the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), and the various state and regional air quality management boards are at the forefront of air quality policy formulation and could be important in the development of environmentally acceptable substitutes for toxic substances. Thus, to promote greater public sector interest in the development of Vernonia and Jatropha and to ascertain the current industrial trends in "clean air" product development, an information exchange was held on December 14, 1989 at the Washington, D.C. offices of Fintrac, the agricultural and agribusiness division of RCG/Hagler, Bailly, Inc. Key government and research organizations sent representatives to this exchange. The following section summarizes the salient issues raised during the information exchange. The exchange's schedule and participants are listed in Appendices A and B, respectively.

SECTION 2: DISCUSSION OF KEY INFORMATION EXCHANGE ISSUES

2.1 REVIEW OF CLEAN AIR LEGISLATION

To help catalyze the discussion of industry's response to clean air legislation, Mark Rockel, senior environmental economist at RCG/Hagler, Bailly, presented an overview of general guidelines that various environmental regulatory agencies, particularly in air quality management, have established to help produce a cleaner environment. Since the ultimate purpose of this dialogue was to view the potential of the Vernonia and Jatropha plants as feedstocks for oil-based paints and diesel fuel, Dr. Rockel's presentation focused on the environmental policy relative to those products.

The federal government has established measures for clean air known as the National Ambient Air Quality Standards (NAAQS). These standards include measurements of NOx, SOx, and volatile organic compounds. Proposed Clean Air Act legislation is aimed at 1) lowering existing NAAQS to produce air clean enough for today's more stringent environmental requirements, 2) enforcing existing pollution standards (e.g., bringing to standard various non-attainment areas), 3) incorporating standards for toxic air pollutants such as carcinogenic hydrocarbons (e.g., BAP, BGP), and 4) installing incentives whereby industry can realistically abide by standards established for a given region; an example was given for the purchase of "pollution licenses."

Air quality control also has been addressed at the regional level, most notably by the South Coast Air Quality Management District (SCAQMD) in California. This board is responsible for establishing air quality standards for southern California and, to date, has set the most stringent policy in the country. For example, Southern California is interested in reducing fuel emissions to such a degree that the Los Angeles City Council has proposed to eliminate all gasoline burning engines by 1996.

Dr. Rockel indicated that the SCAQMD has taken the initiative at a regional level because the Reagan Administration encouraged less national and more local involvement in issues which they considered better administered at a non-national level. This has hindered, somewhat, nationwide industries from developing cleaner products, as there are variable emission standards throughout the country. This reduces market potential (and, thus development incentive) for a given product (e.g., why should industry develop an expensive, low-VOC oil-based paint when it is applicable to just the Los Angeles-area market).

One target for clean air legislation is fuel quality. Fuel quality is assessed by measuring, among other things, the SOx, particulate emissions (PM), and aromatic hydrocarbon contaminants released from combustion in motor vehicle engines. Using this approach the SCAQMD is requiring that methanol be substituted for gasoline and become the motor vehicle fuel in the Los Angeles area before the end of this century.

Air quality improvement also requires a reduction in the emissions from paint spraying. The critical measure in this area is the VOC emission. Conventional oil-based paints used in architectural coatings are particularly high in VOCs. Again, the approach is to find cleaner products (e.g., lower VOC coatings) that can be substituted for these contaminants.

2.2 FACTORS INFLUENCING SUBSTITUTE DIESEL FUEL AND OIL-BASED PAINT PRODUCT DEVELOPMENT

Having discussed the need to provide cleaner products as a means to meet clean air standards, Dr. Rockel addressed the key factors that determine the viability of a potential substitute product or material.

Foremost in this analysis is the size of the diesel fuel market. Current U.S. diesel fuel consumption is 2.4 million barrels per day (mbbl/day). Of this, 1.2 mbbl/day is consumed in highway transportation. The enormous size of this market requires that a prospective substitute have a near-term production volume that will enable a reasonable market penetration. It will thus be important to determine the expected near-term production capacity of Jatropha oil in sub-Saharan Africa and how it relates to U.S. diesel fuel consumption (e.g., 1% of the daily U.S. diesel fuel consumption is 24,000 barrels or approximately 1 million gallons).

Similar market information was provided by Don Anderson, agricultural consultant at Labat-Anderson, on the market for oil-based paints. A 100% replacement of the high-VOC solvents used in oil-based paints would create an annual market of 160 million pounds of solvent. Because this is also a relatively large market, the production/market compatibility issue is also relevant to Vernonia oil.

The performance of the substitute relative to the conventional product is another important factor in assessing commercial potential. Substitute fuels should be analyzed for their engine performance and wear, and coatings for their durability and substrate adhesion. Implicit in this analysis is the requirement that potential substitutes undergo rigorous pilot testing in actual commercial environments.

Consideration must also be given to competition from other substitutes. Dr. Rockel pointed out that previous investigations have shown that existing diesel fuel additives and/or substitutes would add $0.04-0.065 to the per gallon price (adequate U.S. production of these substitutes would require a capital investment of $6.6 billion). New paint substitutes must consider both competing material and technology alternatives (e.g., water-borne delivery systems, expanded latex use, and powder coatings).

Other miscellaneous factors influence commercial viability. Dr. Rockel noted that high sulfur content in fuel causes excessive engine wear. If low-sulfur fuels were used, the decreased maintenance and increased engine life would save U.S. consumers approximately $2 billion per year.

2.3 VERNONIA

2.3.1 Background

The Vernonia plant has been considered as a source for substitutes in high-VOC solvents such as those found in oil-based paints. Mr. Anderson presented information on the history and current status of work performed on the Vernonia plant. He also provided copies of literature on previous studies of the plant (see Appendix C: Previous Research on Vernonia Plant and Oil).

Mr. Anderson stated that the Vernonia is an indigenous sub-Sahara African plant known for its high oil-content seed. Test plots of Vernonia in the U.S. in the 1960s yielded poor results due to low seed retention. However, trials on 1/3 hectare plots in Zimbabwe have produced 2.5 metric ton (seed)/hectare. Using the potential U.S. market of 160 million pounds/year as a basis, Mr. Anderson and the MDI group project this could employ 400,000 people in the farming, collection and crude processing of the Vernonia plant in Africa (a document provided by Mr. Anderson, "Vernonia galamensis, A New Industrial Oilseed Crop for the Semi-Arid Tropics and Subtropics", by Robert E. Perdue, projects that the annual production of 160 million pounds of Vernonia oil would require 365,000 acres).

2.3.2 Current Status

Mr. Anderson commented specifically on the production aspects of the Vernonia plant. He mentioned that technical and preliminary cost analyses of the Vernonia oil extract are being made at the Coatings Research Institute (CRI) in Ypsilanti, Michigan. The director of this program, John Graham, was in attendance at the information exchange, and he brought to the discussion results of the CRI studies.

According to Dr. Graham, the initial technical analyses showed that Vernonia performs quite well as an epoxy substitute in oil-based paints, although there has been insufficient raw material available to conduct thorough performance trials. In fact, Dr. Graham pointed out that the lack of pure Vernonia oil in the U.S. (about 1 gallon is available) has been the main obstacle in the research phase of the Vernonia investigation (sponsored by the SCAQMD). The participants from the EPA's Office of Research and Development, Air and Energy Engineering Research Laboratory (AEERL), Mike Kosusko, chemical engineer, and Chuck Darvin, mechanical engineer, asked whether any data are available on the toxin release of Vernonia oil-based paints and if Vernonia extends life to such paints. Dr. Graham noted that the lack of Vernonia oil has hindered analyses in this area, but preliminary data show that Vernonia-based paints emit low levels of toxins relative to conventional oil-based paints.

Dr. Graham also mentioned initial cost evaluations of Vernonia oil and cost comparisons to existing solvents. Dr. Graham felt the preliminary cost of Vernonia extract to be $0.60/lb (Mr. Anderson stated the cost to be approximately $0.50/lb). The solvents which Vernonia oil would replace are currently sold at $0.15-0.20/lb. Ken Swanberg, Agribusiness and Finance Officer at the U.S. Agency for International Development, Africa Bureau's Market Development and Investment Group (MDI), commented that Vernonia oil's unit cost was a function of production volume and that the insufficient production to date does not allow an appropriate cost comparison analysis. Dr. Swanberg said that the Vernonia project is at the stage where increased funding is needed to better determine such information as unit production costs.

At this point Steven Sides, director, Technical Division of the National Paint and Coatings Association, mentioned that current industrial R&D is aimed at expanding water-borne coating materials and delivery systems. This has significantly reduced the market for solvent and solvent-substitute coatings; market share estimates range from 0.05% (California Air Resources Board) to 1.1% (National Paint and Coatings Association). Hence, industry will likely not commit major R&D funds for solvent-substitute materials such as Vernonia oil. Dr. Graham responded to this by noting that Vernonia oil can also serve the epoxy market; however, no data were offered on cost competitiveness and market size.

2.3.3 Prospective Development

It was apparent from the foregoing discussions that Vernonia oil is a candidate for commercialization in the U.S., but at present, insufficient data are available to quantify its market value. In order to attract support funding for continued Vernonia R&D, MDI will need data from analyses in such areas as product efficacy, product durability and toxic emissions in performance trials and secondary/tertiary markets (e.g., non-coating products).

Dr. Swanberg asked the EPA participants, Messrs. Kosusko and Darvin, if their offices had funds available for extended research in Vernonia oil. They responded that the EPA's Air and Energy Engineering Research Laboratory (AEERL) has limited funds for such projects and that they would like to see more hard data on the air quality performance trials of the Vernonia oil before considering funding such research.

As the leading U.S. research institution in Vernonia oil, the CRI appears to be the best candidate to carry out at least the technical analyses in the aforementioned research areas. Dr. Graham indicated that CRI research staff are positioned for acquiring these and other data when more Vernonia oil is made available for analysis. Dr. Swanberg stated that currently there are Vernonia test plots underway in Kenya (10 hectares) which should provide sufficient oil for conducting the technical analyses.

2.4 JATROPHA

2.4.1 Background

Ken Swanberg presented background information on the Jatropha plant. Jatropha is a small, seed-bearing shrub indigenous to Sub-Saharan Africa. It produces a castor-like oil which is under consideration as a commercial feedstock for combustion engines. Previous studies conducted in Africa and Japan have produced preliminary information on Jatropha's commercial potential.

Jatropha curcas is known primarily for its use as a physical support for the vanilla bean stalk. It also produces a high oil-content seed. As shown in a Japanese study, the Jatropha plant produces 2-3 kgs of seed every five years; the oil content of the seed is 52%. The relatively high calorific value of this oil (9500 kcal per kg.) makes it suitable for use in combustion engines, thus the interest in developing Jatropha as a feedstock for a diesel fuel substitute.

Dr. Swanberg noted that, as an indigenous plant, Jatropha can perform quite well as an intensively cultivated crop in sub-Saharan Africa. Also, performance trials conducted in Japan showed that Jatropha oil significantly reduced particulate emissions emanating from diesel engines.

2.4.2 Current Status

Dr. Swanberg stated that there is no active research program in the U.S. analyzing Jatropha oil as a diesel fuel substitute. His interest at MDI is to encourage both the private and public sectors to pursue further the development of Jatropha as both an agricultural and a commercial product. Josh Epel, an environmental attorney from Colorado, commented that due to the potentially large market for diesel fuel in the U.S., strong consideration must be given to each potential substitute's unit cost. This corroborates Dr. Rockel's information on acceptable additional costs for clean diesel substitutes. Mr. Epel stressed that there is stiff competition in the clean fuel substitute market, particularly from the ethanol industry and that cost data are imperative for an investment analysis. Dr. Swanberg stated that no data are readily available on the unit cost of Jatropha oil.

Mr. Epel also noted that product characterization and performance data such as aromatic and sulfur content (required by the California Air Resources Board and the American Society for Testing Materials), testing, and pipeline compatibility are necessary for comparative substitute fuel evaluations. Also important to such evaluations is information on in-country product storage facilities and transportation costs.

2.4.3 Prospective Development

Mr. Epel stated that much more data (such as those described above) regarding Jatropha unit production cost, potential production volume, and substitute fuel competition are absolutely necessary to better evaluate the U.S. commercial potential of any Jatropha-derived fuel product. He suggested that a thorough review of the Japanese studies would be the logical first step in expanding the Jatropha data base. Using these data, the environmental quality of the Jatropha-based fuel blends can be compared to that of other proposed fuel substitutes (e.g., ethanol and methanol).

Dr. Warren Weinstein, associate assistant administrator of the Africa Bureau/MDI, commented that the information exchange raised more questions than answers with respect to Vernonia and Jatropha. The Africa Bureau is considering a variety of agricultural projects for development in sub-Saharan Africa; the additional product and market data for Jatropha and Vernonia will be important in evaluating their developmental potential in Africa.

SECTION 3: SUMMARY OF PARTICIPANT COMMENTARY

Mark Rockel, RCG/Hagler, Bailly, Inc.

- Current federal Clean Air Act legislation is aimed at bringing to standard various non-attainment regions throughout the country.

- Regional air quality management boards are taking the lead in establishing emission standards for various industries and products.

- When considering new products or substitute materials, industry is concerned about potential market size, unit cost, product quality, and environmental impact.

Don Anderson, Labat-Anderson

- The indigenous sub-Sahara African plant Vernonia has produced high yielding, high quality oil seed on limited (1/3 hectare) test plots in Africa.

- Vernonia produces an oil which can effectively substitute for high-VOC solvents in oil-based paints.

- Previous estimates show the potential U.S. market for Vernonia oil to be 160 million pounds/year, which if produced in sub-Saharan Africa, could provide employment for up to 400,000 people.

Ken Swanberg, AID, Africa Bureau, MDI Group

- Both the Vernonia and Jatropha plants produce well in the sub-Sahara African environment.

- Expanded Vernonia test plots (10 hectares) are in progress in Africa to better assess crop yields and provide more oil for U.S.-based research.
- Jatropha is an oil seed plant which has promise as a feedstock for diesel fuel substitutes.
- Previous Japanese studies have shown that the use of Jatropha oil in diesel fuel reduces particulate emissions in engine combustion.

John Graham, Coatings Research Institute

- Vernonia oil has shown initial good results as a solvent substitute in oil-based paints, both in regard to its performance and environmental behavior.
- Current and future research in Vernonia oil is hindered by the lack of feedstock (only 1 gallon is currently available); he would like to see AID assist in the acquisition of more Vernonia oil.
- Cost estimates of Vernonia oil are $0.60/lb, which are high compared with the solvents ($0.15-$0.20/lb) currently used in oil-based paints.
- Vernonia has commercial potential in the epoxy market, although more market and cost data are needed to better assess this potential.

Mike Kosusko, Chuck Darvin, EPA, Air and Energy Engineering Research Laboratory

- Would like to see hard data on toxin release performance trials of Vernonia oil-based paints.

- EPA's Air and Energy Engineering Research Laboratory has limited funds for off-site research projects.

Steven Sides, National Paint and Coatings Association

- Current industrial paint product development is focused primarily on water-borne materials and delivery systems.
- Competition from other technologies and materials reduces the market potential for solvent-based, and therefore solvent-substitute, paints.
- The Paint and Coating's Association is seeking a set of nationwide standards which industry can use to develop "clean air" products.

Josh Epel, Environmental Attorney, Denver, Colorado

- The additional unit cost is an overriding factor in determining the market potential for diesel fuel substitutes.
- There is much competition in the U.S. substitute fuel market; any prospective fuel substitute promotion must be sensitive to this competition, particularly from U.S.-produced fuels such as ethanol and methanol.
- Data on Jatropha-based fuel performance from the Japanese trials should be acquired to better assess its U.S. market potential.

Warren Weinstein, AID, Africa Bureau, MDI Group

- The information exchange has produced more questions than answers regarding the potential of Vernonia and Jatropha.

- Specific market data and consequent market analysis are needed to properly assess the commercial potential for these plants.

- Detailed information on production and product performance will be necessary for future evaluations of Vernonia and Jatropha.

- A thorough review of the existing literature on Vernonia and Jatropha should be conducted to better define new studies.

- Vernonia and Jatropha are among a number of projects AID's Africa Bureau is reviewing for future funding; competition for these funds requires more extensive analysis, particularly in market-related areas.

SECTION 4: CONCLUDING REMARKS AND RECOMMENDATIONS

The objectives of this information exchange--to 1) determine current industrial trends in the development of environmentally acceptable diesel fuel and high-VOC paint substitutes and 2) discuss the potential for using the African Vernonia and Jatropha plants as feedstocks for oils used as clean substitutes for high-VOC solvents and diesel fuel--were achieved. As has been presented in the preceding summary, perceptive and useful comments delivered by the various participants described the general nature of clean air policies throughout the country and how these policies interact with the development of new, cleaner products.

The dialogue also made clear the need for more information on the potential of Vernonia and Jatropha as agricultural and commercial products. The Market Development and Investment Group at AID is interested in developing markets for sub-Saharan products. Among their objectives is to prompt U.S. business concerns to invest in (e.g., to provide capital and be demand-side joint venture partners) those African projects/products which can provide good earnings for both African and U.S. business participants. The information exchange revealed that there is inadequate technical, environmental, market, and economic information readily available for the prospective investor to effectively analyze an investment proposal in Vernonia and Jatropha.

Vernonia and Jatropha and their potential markets need to be analyzed to obtain a variety of information. Most of the participants at the information exchange had more questions on these plants' market value and product potential than on their technical merits. If market-related issues were the predominant theme of this information exchange (with mostly technical and policy analysts in attendance), then such questioning would only be heightened in a presentation to prospective private investors and financiers. Thus, market or commercial potential is the key issue that MDI needs to address in developing the sub-Saharan investment program. Such analyses must be conducted before (or possibly simultaneously with) the technical investigations. A variety of commercial and market-related factors should be analyzed, including:

- Market identity (specify primary, secondary and tertiary markets)
- Global market size (e.g., 100% market saturation)
- Realistic market penetration
- Compatibility of market penetration with existing production capacity
- Unit production costs (or realistic estimates)
- Competing product pricing
- Margin estimates
- Future product competition (other technologies and/or materials)
- Industrial research and development trends
- Overall capital requirements in farming, processing and storage and transportation
- Customer identity.

These data will permit analyses that will show the business opportunity presented by the development of the Vernonia and Jatropha plants. These analyses should be performed with the same perspective used in developing business plans since it is business, after all, that MDI is seeking to develop.

A promising business perspective (sufficiently encouraging to solicit investment from the private sector) provides the basis for additional technical analyses for proper raw material and product characterization. The information exchange produced a number of potential sources for relevant technical data, including the compendium of Vernonia literature offered in Appendix C of this synopsis. The production-type information needed for Vernonia and Jatropha includes:

- Product toxicology
- Trial performance
- Environmental fate and transport
- Incurred volatile reductions
- Test program costs and constraints (such as the aforementioned lack of raw Vernonia feedstock)
- Intense-cultivation crop yields
- In-country technological inputs (e.g., a schematic analysis for a typical Vernonia farm and processing center)
- Agronomic constraints
- In-country agricultural and export policies
- Detailed research histories.

Additionally, communication among those active in such R&D programs must be coordinated. For example, Fintrac has learned subsequent to the information exchange that an importer in New Jersey can supply Vernonia oil to U.S. buyers in 42-gallon drums upon request. This will provide immediate assistance to Dr. Graham in his search for raw materials to conduct Vernonia research.

MDI will need these detailed market and product/technology analyses to effectively evaluate competing development projects in sub-Saharan Africa. Stiff competition for the limited funds available for business development in this region requires hard data and clear facts so that analysts can make logical decisions on the project proposals. In effect, such analyses will reduce the risk in forthcoming funding and investment decisions. If the information is properly assembled and delivered, it will both assist AID/MDI in deciding on future internal program funding and provide the format for presentations to prospective investors/participants in U.S.-African joint ventures.

APPENDIX A: INFORMATION EXCHANGE AGENDA

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	Topic	Speaker	Time
1.	Introduction	Kerry Sachs, Fintrac Moderator	10 a.m.-10:10 a.m.
2.	Review of Industry Trends in Response to Legislation Promoting Clean Air	Mark Rockell RCG/Hagler, Bailly	10:10 a.m.-10:30 a.m.
3.	Questions		10:30 a.m.-10:45 a.m.
4.	Production Perspective on Vernonia: Clean Substitute for VOCs	Don Anderson Labat-Anderson	10:45 a.m.-11:15 a.m.
4.	Production Perspective on Jatropha: Clean Substitutes for Diesel Fuel	Ken Swanberg AID/Africa Bureau Market Development and Investment (MDI)	11:15 a.m.-11:30 a.m.
5.	Open Discussion	All participants	11:30 a.m.-12 p.m.
6.	Continued Discussion/ Working Lunch	All participants	12:00 p.m.-1:00 p.m.
7.	Conclusion	Kerry Sachs	1:00 p.m.

APPENDIX B: LIST OF INFORMATION EXCHANGE ATTENDEES

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Name	Organization	Phone
Carolyn Alkire	Labat-Anderson	(703) 525-9400
Donald E. Anderson	Labat-Anderson	(202) 647-8909
Russel Backus	USAID/AFR/TR/ANR	(703) 235-0880
Charles Darvin	EPA/AEERL	(919) 541-2734
Joshua B. Epel	Private Attorney/Denver	(303) 820-4194
John Franke	Fintrac	(202) 488-1500
John C. Graham	Coatings Research Institute	(313) 487-2203
Michael Kosusko	EPA/AEERL	(919) 541-2734
Marrin Lewis	USAID/AFR/MDI	(202) 647-7614
Bill Meade	RCG/Hagler, Bailly, Inc.	(202) 488-1500
Tim Mulholland	Labat-Anderson	(703) 525-9400
Mark Rockel	RCG/Hagler, Bailly, Inc.	(202) 488-1500
Kerry Sachs	Fintrac	(202) 488-1500
Phil Sczerzenie	Labat-Anderson	(703) 525-5300 x512

Steve Sides	National Paint and Coatings Association	(202) 462-6272
Sarah Sprague	US Department of Energy	(202) 586-8078
Ken Swanberg	USAID/AFR/MDI	(202) 647-9195
Warren Weinstein	USAID/AFR/MDI	(202) 647-7614

APPENDIX C: PREVIOUS RESEARCH ON VERNONIA PLANT AND OIL

VERNONIA

VERNONIA GALAMENSIS, A NEW INDUSTRIAL OILSEED CROP FOR THE SEMI-ARID TROPICS AND SUBTROPICS

July 15, 1989

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SUMMARY

The seed oil of Vernonia galamensis is a rich souce of vernolic acid, a naturally epoxidized fatty acid. Seed yields of 2225 pounds per acre have been achieved in Zimbabwe.

This plant is insect-, disease-, and drought-resistant and can be developed as a new cash crop in semi-arid tropical and subtropical areas with as little as 8 inches rainfall.

Seed contain about 40% oil with unique chemical (epoxy) and physical (low viscosity) properties. There is a promising market in the manufacture of oil-based (alkyd-resin) paint where it is anticipated that the low viscosity and unique chemistry of the oil will permit its use in the formulation of "reactive diluents", products to serve as solvents that become part of the dry paint surface and do not evaporate to pollute the air.

Volatile organic compounds (VOC) from oil-based paints and other sources react with nitrogen oxides to produce ozone, a deleterious component of photo-chemical smog. An accelerated research program on vernonia-oil reactive diluents is underway at the Coatings Research Institute. CRI projects that at least one pint of vernonia oil can be used in each of the 325,000,000 gallons of oil-based paint produced in the U. S. each year and reduce emissions of VOC by at least 160,000,000 pounds.

The estimated minimum requirement of oil to meet the annual needs of the U. S. paint industry will require the production of 365,000 acres of vernonia.

Other potential markets: "toughened" epoxy resins, epoxy-alkyd paints, dibasic acids, lubricants, and adhesives.

Vernonia will serve as a significant new crop for the third-world farmer to yield a product that will improve environmental quality in industrial areas of the United States.

INDEX

The variety of *Vernonia galamensis* now being developed as a new crop in Zimbabwe. This variety occurs only in Ethiopia where it is found on well-drained soils in semi-arid areas on the lower slopes of the Eastern Highlands. Habit, including root, about x2/5, single flowerhead (bottom) x1, seed (with long hairs on top) and flowers about x4.

C. T. Nyati, between two *Vernonia galamensis* plots at the Chiredzi Research Station, Chiredzi, Zimbabwe, 1987. Plants on the right were "topped". The terminal bud was removed when plants were about six inches tall. There were many branches from the base of the stems, each with several flowerheads. Topping reduces height of plants and enhances uniformity in seed maturity. Yield here in 1987 was 2225 pounds per acre. The response to topping was first observed at the Chipinge Research Station in 1985 by R. Bester. It has been exploited as a management technique at Chiredzi. Nyati's dedication to the vernonia project at Chiredzi has been a major factor in its success.

INTRODUCTION

During the 1950's, the Agricultural Research Service of the U. S. Department of Agriculture initiated screening programs to identify new sources of industrial raw materials - new and unique plant constituents that would not compete with those then in adequate supply and that could be used to satisfy existing or anticipated needs. The goal was to identify plants that might be developed as new crops in the U. S. for agricultural diversification to replace those then in surplus. One program focused on unusual seed oils for which new industrial markets might be created or that might recapture markets lost by agricultural products to petrochemicals. Seed were analysed for oil content and those with substantial amounts were evaluated to identify oils with unique fatty-acid composition, distinctly different from established oilseed crops.

Seed of *Vernonia anthelmintica*, native to India, were a good source of vernolic acid, a natually epoxidized fatty acid. The seed contained 23-31% oil of which 68-75% was vernolic acid.

Since substantial quantities of epoxy oils are used to manufacture plastic formulations, protective coatings, and other products, an effort was made to develope this plant as a new crop for American agriculture. This was unsuccessful; yield was limited by poor seed retention. The seed fell off the plant as soon as they matured. There was a heavy crop but it was not adaptable to mechanical harvest.

Later, *Vernonia galamensis*, an African species, was observed to have good seed retention and to be a superior source of vernolic acid. The seed contain about 40% oil of which about 80% is vernolic acid.

Vernonia galamensis has been under development as a new crop in Zimbabwe since 1983. All research to date has been with crude unimproved germplasm collected in a dry area of Ethiopia in 1964, an accession almost tailor-made as a new crop. This germplasm is very uniform; there has been no selection of improved varieties.

VERNONIA GALAMENSIS BIOLOGY

This summary is based on information from small preliminary trial plantings at 15 locations in Arizona, Georgia, Jamaica, Puerto Rico, Taiwan, Ethiopia, Kenya, Tanzania, and Zambia; more extensive trials in Zimbabwe in 1983-88; evaluation in Pakistan in 1977-84; field observations of wild populations in Kenya and Ethiopia in 1988; a recent indepth taxonomic study based on many plant specimens collected from natural stands in Africa; and laboratory analyses of seed and oil.

- Annual herb, seed germinate easily.
- Grows naturally in Africa in areas with as little as 8 inches seasonal rainfall and thus is adapted to areas unsuitable or only marginally suitable for food crops.
- Weed, always in disturbed areas and thus more suitable for cultivation than non-weedy species.
- Plantings in Kenya and Zimbabwe confirmed the good seed retention first observed in a natural stand in Ethiopia.
- Resistant to insects and diseases.
- Tolerates extreme heat so long as soil moisture is adequate.
- Requires a well-drained soil.
- Seed yield in Zimbabwe, up to 2225 pounds per acre, exceeds average yield of soybeans in the United States. (In comparison, the yield of soybeans in the United States in 1979, the best year from 1970-84, was 1926 pounds per acre.)
- Tolerates substantial shade; an ideal cash crop for agro-forestry.
- Taxonomically diverse (six subspecies, one with four taxonomic varieties); thus, great genetic diversity for developing improved varieties.
- Seed contain approximately 40% oil (twice the oil content of soybeans) which is a rich source of vernolic acid, a naturallly epoxidized fatty acid. Oil contains about 80% vernolic acid.
- Meal (seed from which oil has been extracted) is a rich souce (40%) of protein, a valuable by-product.

31

POTENTIAL SEED YIELD

In 1985, seed yield in Zimbabwe was about 1200 lbs. per acre. Agronomists predicted they could double the yield by learning how to manage the crop and triple the yield by breeding when more germplasm is available.

A chance observation in 1985 led to "topping", a management technique still being perfected, which in 1987 resulted in a yield of 2225 lbs. per acre. Plants are topped by removing the terminal bud when they are about 6 in. high. There are many branches from the base of the stem each of which produces several flowerheads. Height of plants at harvest is significantly reduced and uniformity in seed maturity is greatly enhanced.

A further substantial increase in yield by breeding better varieties is a reasonable expectation. When soybeans were first grown in the U. S. as a seed crop during the 1920's, yield was about 11 bushels per acre. Today, after investment of many hundreds of scientist-years in soybean research, the average yield in the U. S. is 34 bushels per acre and still increasing.

The Zimbabwe investment in vernonia: about one-fourth the time of a Research Officer per year for five years.

VERNONIA GALAMENSIS OIL

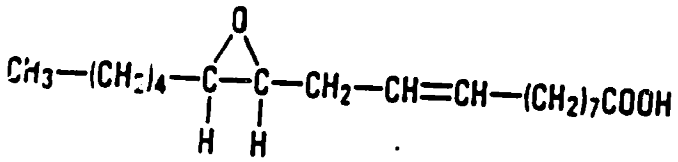
Currently, vernonia oil is produced by solvent extration, the same process used for soybean oil.

Chemically, the oil is similar to epoxidized soybean and linseed oils, but there is an important difference, one that can be exploited to avoid competing with these agricultural products. Epoxidized soybean and linseed oils are highly viscous (300-1500 cps); they are semi-solids at 50° F. and are non-pourable below 32° F. In contrast, vernonia oil has low viscosity (110 cps); it is pourable even below 32° F.

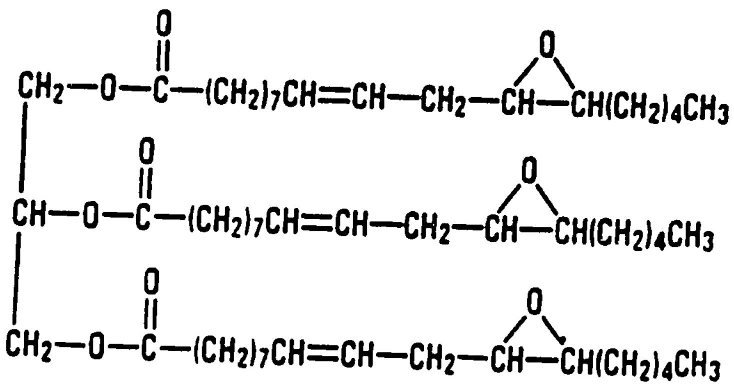
Vernonia oil contains 78-80% vernolic acid, 12-14 % linoleic acid, 4-6% oleic acid, 2-3% stearic acid, 2-3% palmitic acid and a trace amount of arachidic acid.

The oil is an especially attractive raw material for industry because it is so rich in a single fatty acid. For example, in comparison, soybean oil contains just 55% linoleic as it principal fatty acid and linseed oil contains just 57% linolenic acid.

Vernolic acid:



is primarily present in the oil as the triglyceride trivernolin:



It is the epoxy groups (the oxygen atom attached to two carbon atoms) of such triglyceride oils that make these materials useful in plastics and coatings. They serve as highly reactive sites where one triglyceride molecule can become attached to adjacent molecules, and these to others, to form interlocking polymer networks.

MARKET PROSPECTS FOR VERNONIA OIL

Approximately 325,000,000 gallons of alkyd-resin (oil-based) paints are produced in the United States each year. The volatile organic compounds (VOC) in these products react with nitrogen oxides in the presence of sunlight to create ground-level ozone, the deleterious component of photo-chemical smog. Ozone is a serious problem in all industrial areas; it is especially serious in California's Los Angeles Basin where emissions of VOC from paints and varnishes used by the wood-products industry are 22 tons per day.

Dr. Stoil K. Dirlikov, Coatings Research Institute (CRI), Eastern Michigan University, recently initiated research on vernonia oil to develope "reactive diluents" for "high-solids" coatings. This research will exploit the unique physical and chemical properties of the oil. CRI proposes that the low viscosity wil permit the oil to be used a solvent in an alkyd-resin paint, one which (because of its chemistry) will become part of the dry paint surface and not evaporate to pollute the air.

CRI estimates that conservatively, at least one pound of vernonia oil can be used in each gallon of paint to reduce VOC by at least 160,000,000 pounds per year. This will create a market for the oil production from at least 365,000 acres of vernonia, a substantial market based just on the needs of American industry.

CRI research on vernonia oil will be sponsored by the South Coast Air-Quality Management District (the Los Angeles Basin pollution control agency), U. S. Agency for International Development, PRA (formerly Paint Research Associates, an industry group), and a State of Michigan development fund.

Once his research on reactive diluents is underway, Dr. Dirlikov plans research on the use of vernonia oil in the formulation of "toughened" epoxy resins. According to him, there are so many epoxy-resin formulations that chances of success are near 100%. Epoxy resins have two important disadvantages. They are brittle and absorb water (important in electronic applications). Dirlikov believes that formulation of these resins with 10-15% vernonia oil will make them less brittle and reduce their water absorbtion.

Dr. Kenneth D. Carlson, Northern Regional Research Center, ARS, USDA, used vernonia oil for baked coatings on steel panels. Properties were outstanding. The coatings had good flexibility, resistance to chipping, excellent adhesion, etc. There was good resistance to alkali, acid, and solvents. More research is needed but this is a promising potential application because baked coatings produce little if any VOC.

Dr. Folahan O. Ayorinde, Department of Chemistry, Howard University, is currently synthesizing "dibasic" acids from vernonia oil. These products, now obtained primarily from petroleum, are used to manufacture industrial nylons. Dr. Ayorinde is also synthesizing "interpenetrating polymer networks" (tough rubbery materials) from the oil. His research is sponsored by the U. S. Department of Agriculture's Office of International Cooperation and Development.

Research on the oil is also underway at another industrial laboratory, which has requested anonymity. It is focused on an application different from those mentioned above.

The Senior Research Chemist at this laboratory was asked: " What is it about vernonia oil that suggests to you it might enter markets where it will not compete with epoxidized soybean oil? Do you see a particular industrial need that might be met by vernonia oil where the end product is of such high value that a manufacturer might be able to pay a premium price for vernonia oil?

The response: "...without giving away any proprietary information...we use epoxidized soybean oil and are quite familiar with it. Wherever it is possible to use epoxidized soybean oil, we do. It's not in this vein that we are anticipating using the oil from Vernonia galamensis. The reason for this is that we are trying to push our products more and more into the higher added-value specialty chemicals and its the chemistry of the (vernonia oil) epoxy fatty acid, the relatively high degree of purity of that material within the oil that attracts us. It is the particular chemistry and the simplicity of the chemistry that attracts us to it.....converting the epoxy fatty acid into a functional ingredient of one of our finished products. The reason we think this material doesn't compete in any way with epoxidized soybean oil... Traditionally, (our products) have been derived from chemicals which are now almost of commodity value. To establish high margins and a competitive edge, one has to move more and more toward novelty, and this is tantamount to moving more toward high-added-value specialty chemicals. We are looking toward materials in our future products which confer particular benefits,...which are based on the high-added-value ingredient. This is the way we think we will gain an edge over the competition in what is very much a cost-driven commodity type market. We are looking to seek an edge over our competitiors by engineering (valuable properties) into our products which we feel will almost certainly come from materials which are higher in value than the current generation of components used."

VERNONIA GALAMENSIS GERMPLASM FOR CROP IMPROVEMENT

All trial plantings to date have been with the original crude germplasm collected in Ethiopia in 1964. This is a very uniform accession and offers little opportunity for selection of improved varieties.

Vernonia galamensis is a very diverse species. According to M. G. Gilbert's 1986 taxonomic study (with which Jeffrey, 1988, is in substantial agreement) there are six subspecies, one with four distinct varieties. There is more than ample genetic diversity for crop improvement. The center of diversity is in Kenya.

Thirty-two new germplasm accessions (at least one of each subspecies and taxonomic variety) have been assembled, but more will be needed. All new accessions are currently under evaluation and already we are beginning to see important variation to photosensitivity.

While the original germplasm from Ethiopia is tailor-made as a new crop, with broad genetic diversity, much can be done to develope improved varieties. Achievable goals:

- Combinations that are not photosensitive or with different photosensitivity.
- Increased seed production with combinations that invest more energy in seed and less in stems and leaves.
- Higher oil yield with increased vernolic acid in the oil
- Even better drought resistance.
- Better seedling vigor to reduce need for weed control.
- Disease and insect resistance if needed later.
- Adaptability to moderately drained soils.

Agronomic research in Zimbabwe points to a challenge that can be met by breeding and improve the economics of seed production. The graph on the following page shows average monthly rainfall and temperature at Triangle Hill, Zimbabwe, a weather station near the site of agronomic trials at the Chiredzi Research Station.

The ideal planting time is in November at the beginning of the rainy season. But regardless of when vernonia is planted from November to February it will not flower until April because of its response to daylength. The best planting time is February. With flowering so late, seed mature during "winter" and maturity is delayed because of the high energy requirement to mature an oilseed crop. Time from planting to harvest (6-7 months) is unduly long. This increases chance of some "disaster" like high winds that might destroy the

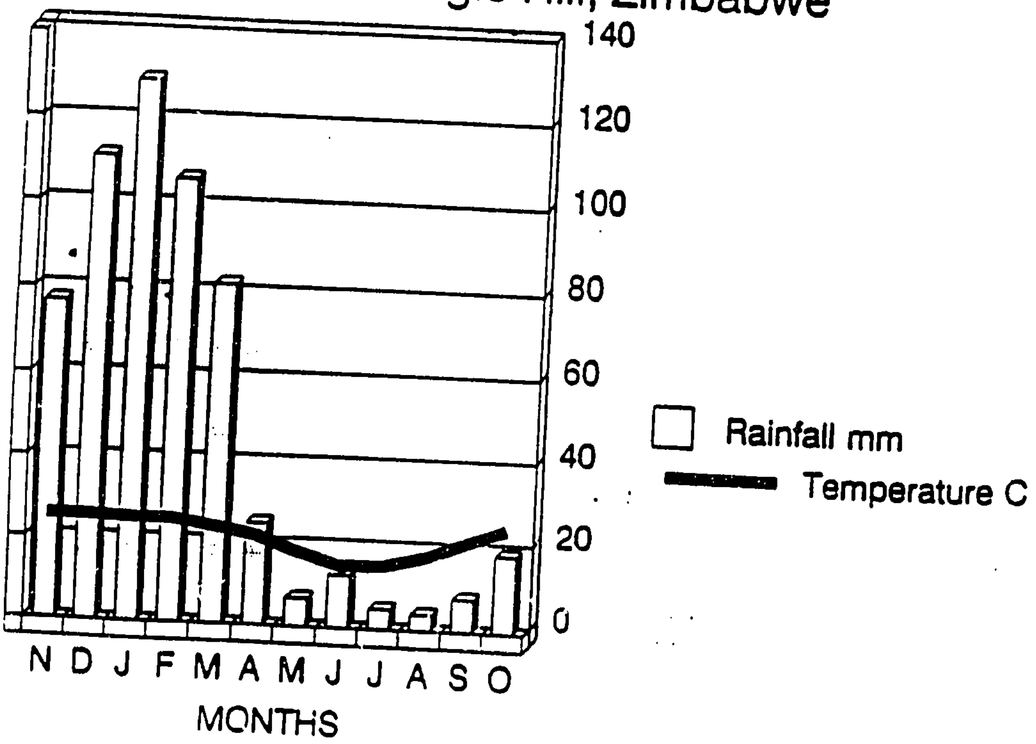
VERNONIA GALAMENSIS GERMPLASM FOR CROP IMPROVEMENT (CONTINUED)

crop. And the farmer will not be able to use his land for a winter crop like cabbage. But, more important, the crop is not synchronized with the rainy season so must be irrigated. There is adequate rainfall for vernonia but only if it can be planted earlier.

A variety is needed here with different response to daylength, preferably one that can be planted by about mid-December, flower by mid-February, and produce mature seed by about mid-April. In 1988, new germplasm from Nigeria was grown out at the Coastal Plain Experiment Station, Tifton, GA where it flowered in late summer almost two months earlier than the original germplasm from Ethiopia. The latter flowered just before frost.

During the winter of 1989, three new accessions from Kenya flowered in a Coastal Plain Experiment Station greenhouse in response to long days (16 hours). One of these accessions is of special interest because it has the best drought resistance so far observed in *V. galamensis*

Germplasm from Sudan, where *V. galamensis* grows naturally most distant from the equator in a semi-arid environment, will provide additional variation in response to daylength. This is clearly evident from time of collection of herbarium specimens in relation to the rainy season. This germplasm offers another opportunity. Some plants with mature seed are only 6-10 in. tall, plants that must have produced a seed crop in less than three months.



Average Monthly Rainfall and Temperature

Triangle Hill, Zimbabwe

IS VERNONIA READY FOR DEVELOPMENT?

Currently, no certain market has been identified for vernonia oil but this is a very versatile raw material for industrial applications and it can be produced very economically. The future is very bright. The great hope for a market is as a reactive diluent in alkyd-resin paints and prospects are very good that a market will be identified based on this application within three years. Other prospects: epoxy-alkyd paints, toughened epoxy resins, adhesives, and lubricants.

What comes first, the cart or the horse? When the first polio vaccine was developed there was a severe shortage. The reaction of one high-ranking U. S. official: "Who could have anticipated the demand?"

We must anticipate the demand and be prepared to meet it. A gamble yes, but at very small cost, one that can yield tremendous benefit to the third-world farmer.

It would be premature to establish thousands of acres but very timely for development workers to establish modest trial plantings at carefully chosen sites in selected countries to:

- Learn how to manage the crop so as to later advise farmers on production.
- Assure the supplies of oil that will be needed by industry for large scale pilot-plant evaluations.
- Increase seed so they will be available for production plantings to meet future market needs.

VERNONIA LITERATURE

This bibliography includes papers on utilization of oil from *V. anthelmintica* that are pertinent to V. *galamensis*.

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Krewson, C. F., G. R. Riser and W. E. Scott. *Euphorbia* and *Vernonia* seed oil products as plasticizer-stabilizers for polyvinyl chloride. J. Am. Oil Chem. Soc. 43: 377-379 (1966).

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Phatak, S. C., C. A. Jaworski, and R. E. Perdue, Jr. Response of *Vernonia galamensis* to photoperiod. (abstract of paper presented at Am. Soc. Horticultural Sci. S. Region, Nashville, TN, February 5-8, 1989). Hort. Sci. (in press) Manuscript to be submitted to Hort. Sci.

Riser, G. R., J.J. Hunter, J. S. Ard, and L. P. Witnauer. *Vernonia anthelmintica* Willd. seed oil and salts of vernolic acid as stabilizers for plasticized poly (vinyl chloride). J. Am. Oil Chem. Soc. 39:266-268 (1962).

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VERNONIA RESEARCH AND DEVELOPMENT PROJECTS

Samples of vernonia oil have been requested by 13 industrial laboratories, five of which are interested in formulation of reactive diluents for oil-based paints. Other interests: epoxy resins, lubricants and lubricant additives, plasticizers, and adhesives.

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A symposium on Vernonia galamensis at the First Annual Conference of the Association for the Advancement of Industrial Crops, Peoria, IL, October 2-6, 1989, will include reports on much research in progress. Symposium Chairman: John C. Graham, Director, Coatings Research Institute, Ypsilanti, MI.

(Abbreviations: ARS - Agricultural Research Service; BD - Botany Department; CD - Chemistry Department; HU - Howard University, Washington, DC; NRRC - Northern Regional Research Center; SRRC - Southern Regional Research Center; USDA - U. S. Department of Agriculture)

J. S. Adkins, Department of Human Nutrition and Food, HU, F. O. Ayorinde, CD/HU, and R. L. Shepard, CD/HU. Protein quality of Vernonia galamensis defatted flake.

R. Adlof, H. Rakoff and E. Emken, USDA/ARS/NRRC, Peoria, Illinois. Utilization of vernonia oil in the synthesis of deuterium-labeled and unlabeled fatty acid isomers. (Vernolic acid is a versatile intermediate that can be used for synthesis of deuterated fatty acids containing double bonds in a variety of positions and configurations. These deuterated fatty acids are fed to human volunteers to study how they are metabolized. The objective is to determine the effect of chain length and position and configuration of the double bond on lipid metabolism and the nutritional consequences of consuming different kinds of fats.)

F. O. Ayorinde, V. N. Parchment, B. M. Bernard and E. Y. Nana, CD/HU. Oxidative and lipolytic products from Vernonia galamensis oil. (Synthesis of dibasic acids, oxo-acids and toughened elastomers from vernonia oil; oil extraction and refining (including bleaching) and lipase activity.)

S. Belay and K. Sood, PHYTOTEC, c/o Integrity Bioservices, Inc., Rockville, MD, J. Rier and S. Obasi, BD/HU, and F. O. Ayorinde, CD/HU. In vitro culture of Vernonia galamensis and its potential for oil improvement.

K. D. Carlson, USDA/ARS/NRRC, F. O. Ayorinde, CD/HU, R. P. Pavlik and J. McVety, The French Oil Mill Machinery Co., Piqua, OH. Pilot plant extraction of oil from Vernonia galamensis seed.

41

VERNONIA RESEARCH AND DEVELOPMENT PROJECTS (CONTINUED)

S. K. Dirlikov, Coatings Research Institute, Eastern Michigan University, Ypsilanti, MI. Applications of vernonia oil in coatings and epoxy resins.

M. Mumbila, Department of Biochemistry, University of Zimbabwe. Transcription and mapping of Vernonia galamensis genome (chloroplast/nucleus).

R. E. Perdue, Jr., USDA/ARS, Beltsville, MD. Vernonia galamensis: botany and agronomy.

S. C. Phatak, University of Georgia, Tifton, C. A. Jaworski, USDA/ARS Tifton, GA and A. E. Thompson and D. A. Dierig, USDA/ARS, Phoenix, AZ. Reponse of Vernonia galamensis to photoperiod.

J. Read, Department of Biochemistry, University of Zimbabwe, Harare, Zimbabwe. Vernonia galamensis lectins.

R. L. Shepard, CD/HU, and M. O. Ologunde, CD, Obafemi Awolowo University, Ile-Ife, Nigeria. Chemical evaluation of Vernonia galamensis defatted flake.

E. B. Shultz, Bioresources Development Group, Department of Engineering and Policy, School of Engineering and Applied Science, Washington University, St. Louis, MO. Economic analysis and market potential.

L. H. Sperling, Departments of Chemical Engineering and Materials Science and Engineering, Lehigh University, Bethlehem, PA. Vernonia oil based interpenetrating polymer networks.

The research of Drs. Adkins and Ayorinde, Howard University, is supported by a grant from Office of International Cooperation and Development, USDA.

Dr. Dirlikov's research at the Coatings Research Institute is funded by grants from the South Coast Air Quality Management District (California), PRA (formerly Paint Research Associates) and Michigan State Research and Development Fund. An additional grant is anticipated from the U. S. Agency for International Development's Program in Science and Technology Cooperation.

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42

VERNONIA RESEARCH AND DEVELOPMENT PROJECTS (CONTINUED)

Other research and development projects:

A. G. Berlage, National Forage Seed Production Research Center, USDA/ARS, Corvallis, OR. Seed cleaning. Vernonia seed are now cleaned by hand because production is not large enough to justify use of large-scale cleaners. The objective of this project is to identify equipment that experiment stations and small farmers can use to mechanically clean seed.

B. Eribo, Botany Department, Howard University, Washington, D.C. Fermentation of vernonia oil with soil microorganisms.

J. Jakupovic, Organic Chemistry Institute, Berlin Technical University, West Germany. Minor constituents of vernonia roots, foliage, seed, oil, and seed meal. (Many species of vernonia produce small amounts of toxic materials. It is reasonable to assume this is true of V. galamensis and that such constituents are concentrated in the seed. This research will identify these constitutents, if present, and provide clues as to how the seed meal can be de-toxified, if necessary, for use as livestock feed.)

H. G. Larew, Florist and Nursery Crops Laboratory, Beltsville Agricultural Research Center, USDA/ARS, Beltsville, MD. Evaluation of vernonia oil as an insecticide and insect repellant.

C. G. McWhorter, Southern Weed Science Laboratory, ARS/USDA, Stoneville, MS. Formulation of crop-oil-concentrates with vernonia oil. (According to Dr. McWhorter, "COC's are widely used as spray adjuvants in tank mixture with herbicides......The epoxidized residue of vernonia oil should aid in binding the herbicide to plant surfaces.")

I. Mharapara and E. Jones, Chiredzi Research Station, Department of Research and Specialist Services, Ministry of Lands, Agriculture, and Rural Ressetlement, Chiredzi, Zimbabwe. Vernonia agronomy (1983 to date).

A. Pepperman, Composition and Properties Research, USDA/ARS/SRRC, New Orleans, LA. Formulation of slow-release pesticides and herbicides with vernonia oil. (to reduce ground-water pollution).

WHAT IF??? - VERNONIA OIL VS. PETROCHEMICALS

The great hope for an immediate market for vernonia oil is in the paint industry. But what if this does not materialize? Then, vernonia oil will have to compete with petrochemicals. Will it be able to compete? We hope to get a better answer to this question through the research of Dr. E. B. Shultz. But, even now, vernonia prospects look very good. It is not so much a question of will vernonia oil be competive - but, when will it be competitive?

The price of petroleum will increase DRAMATICALLY.
and that increase is just around the corner.

- "The first 200 billion barrels of world oil were produced and consumed in 109 years (1859-1967)." (CRS Review, March 1988)
- "Just 10 years were needed to produce and consume the next 200 billion barrels (1968-1977)." (CRS Review, March 1988)
- Current petroleum consumption: <u>20 billion barrels per year</u>.
- "It is unlikely that any one unexplored region of the world remains that contains 20 billion barrels of recoverable oil (the amount currently produced in one year)." (CRS Review, March 1988)
- "Little of the world's petroleum is likely to remain by the bicentenial of the world's first oil well in the year 2059." (State of the World, 1986)
- "Recent independence from Middle Eastern petroleum has occurred largely at the expense of greater long-term dependence." (State of the World, 1986)
- Proven oil reserves in billions of barrels (DOE Annual Energy Outlook, 1987):

  OPEC: 671, Non-OPEC: 216 (total 887)
  (Middle East: 566, Western Hemisphere: 146, Communist World: 79, Other:96)
- Projected world oil prices in the year 2000 (DOE Annual Energy Outlook, 1987):

  Base estimate: $31 (low: $25, high: $40)
- Projected world oil prices in the year 2010 (a DOE "don't quote me" estimate):

  Base estimate: $36 (low: $30, high: $45)
- "....with long-term oil demand increasing and non-OPEC supplies peaking, OPEC will be able to impose an oil price structure of their choosing sometime early in the 1990s." "Increasingly, future demand for oil and gas has to be met by more expensive production from smaller, more complex, harder to find reservoirs." (Schlumberger Annual Report 1988)

WHAT IF??? (CONTINUED)

- "Current oil prices are too low to be sustained in the 1990s. Stephen Brown and Keith Phillips forecast that by the year 2000, the price of oil (in 1988 dollars) could reach $30 to $40 per barrel." (Economic Review, January 1989. Brown and Phillips are economists with Federal Reserve Bank of Dallas.)

- "When the cost of gasoline to the American consumer is twice what it is today, you will see a great deal of interest in vernonia oil." (L. H. Sperling, Materials Research Center, Lehigh University, when petroleum was $18 per barrel. Dr. Sperling used vernonia oil in his research on "inter-penetrating polymer networks".

- "The price of petroleum has come down." (A Dupont research scientist in 1987. When I was sure a substantial supply of oil would be available, I began contacting industry laboratories. The response was encouraging and oil samples were sent to them. A year later the samples were still on the shelf.)

A MODEST INVESTMENT IN VERNONIA NOW WILL PAY DIVIDENDS LATER, THE ONLY QUESTION IS WHEN.

ROYAL
BOTANIC
GARDENS
KEW

Royal Botanic Gardens Kew, Richmond, Surrey. TW9 3AB England

Dr Robert E. Perdue, Jr.,
Botanist, Systematic Botany,
Mycology and Nematology Laboratory,
Building 265,
BARC-East,
United States Department of Agriculture,
Beltsville, Maryland 20705,
U.S.A.

OUR REF. GW
4 November 1987

Dear Bob,

I am now editing the papers presented at the Southampton Conference on 'New Crops for Food and Industry', to be published by Croom Helm Ltd. later next year. Your paper was the only one that discussed a genuine new crop with the potential for an economic plant and it seems appropriate therefore that a colour photograph of Vernonia should be used for the frontpiece to the proceedings. I hope you are agreeable and able to provide a suitable photograph.

My impression at the end of the Conference was that most of the so called 'new crops' under discussion were not new. Many of them were old crops that had fallen into disuse and were being revived to meet a new market-market potential while others were unlikely to make more than a local impact. Although food crops are essential to man's survival, there is nevertheless a need for industrial crops as well. Of all the new crops discussed Vernonia was the outstanding example of one most likely to have an industrial impact and I wish you well in its development.

Yours sincerely,

Dr G.E. Wickens
ECONOMIC AND CONSERVATION SECTION

Vernonia galamensis, Potential New Crop Source of Epoxy Acid[1]

ROBERT E. PERDUE, JR.,[2] KENNETH D. CARLSON,[3] AND
MICHAEL G. GILBERT[4]

Vernonia galamensis *is a good source of seed oil rich in epoxy acid, which can be used to manufacture plastic formulations, protective coatings, and other products. Seed from a natural stand in Ethiopia contained 31% epoxy acid. Under cultivation in Kenya, this unimproved germplasm produced a substantial yield of seed with 32% epoxy acid. This African species has good natural seed retention and is a promising new crop for semiarid tropical areas.*

During the mid-1950s the USDA Agricultural Research Service initiated plant screening programs to identify new sources of industrial raw materials, especially new and unique plant constituents that would not compete with those then in adequate supply and that could be used to satisfy existing needs or anticipated needs. The goal was to identify plants that might be developed as new crops for agricultural diversification to replace those in surplus.

One program focused on the discovery of unusual seed oils for which new industrial markets might be created or that might recapture markets lost by agricultural products to petrochemicals. Seeds were screened for oil content and those with substantial amounts ($\geq 20\%$) were evaluated to identify oils with unique fatty-acid composition, distinctly different from oils of peanut, cottonseed, soybean, linseed, or other domestic crops.

Oil content of *Vernonia anthelmintica* (L.) Willd. seed obtained from the Indian Agricultural Research Institute (IARI), New Delhi, was 26.5% (Earle et al., 1960). Preliminary evaluation of the oil, including evaluation for oxirane oxygen (an indication of the degree to which the double bonds of a fatty acid [-C=C-] have been replaced by epoxy groups (Fig. 1), indicated the presence of an epoxy oleic acid in the amount of 67%. Earlier, Gunstone (1954) had discovered vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic acid) (Fig. 1A) in seed oil of the same species, and vernolic acid was subsequently isolated from the seed supplied by IARI (Smith et al., 1959).

Since substantial quantities of epoxy oils were then, and still are, used by industry to manufacture plastic formulations, protective coatings, and other products, prospects seemed good that a naturally occurring epoxy acid could enter these markets and perhaps others developed following further utilization research on the oil. Existing needs were met with petrochemicals or by chemical modification (epoxidation) of fats and vegetable oils, notably soybean and linseed oils. Epoxidizing these inexpensive and readily available vegetable oils increases their

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[1] Received 1 November 1984; accepted 28 June 1985.

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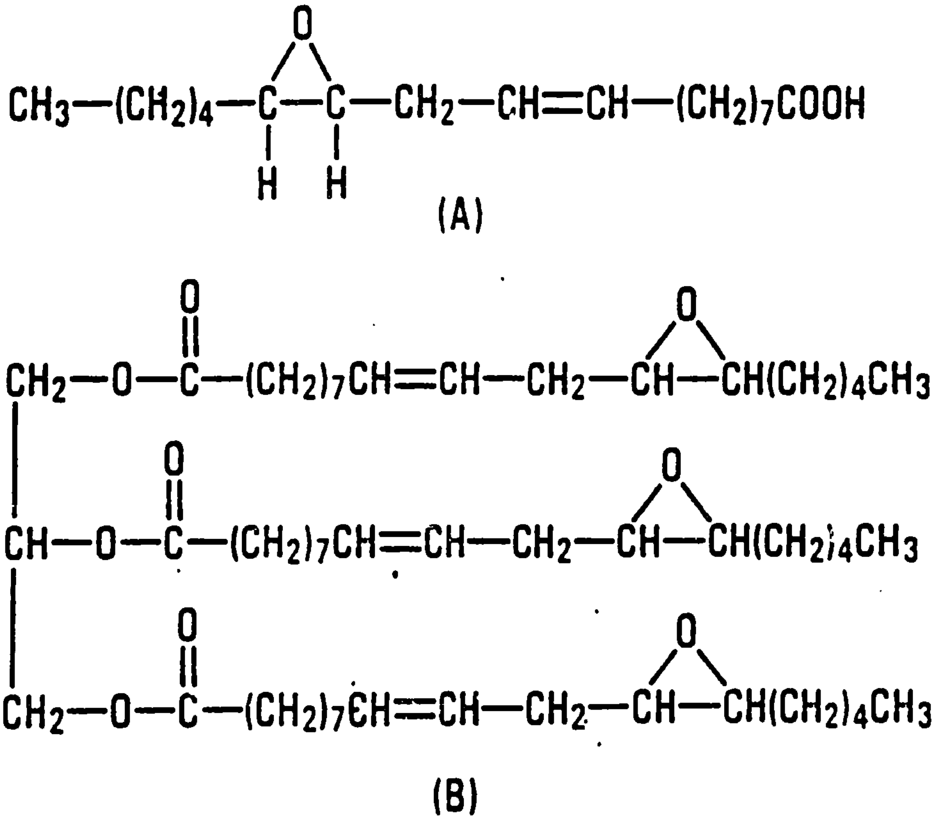

Fig. 1. Vernolic acid (A) and trivernolin (B).

value two- to threefold. It is the epoxy groups of such triglyceride oils that make these materials useful in plastics and coatings products. They serve as plasticizers (for flexibility), stabilizers (to inactivate agents in plastics that otherwise cause them to degrade), and generally as highly reactive sites where one triglyceride molecule can become attached to adjacent molecules, and these to others, to form interlocking polymer networks.

Thus, a program was initiated to introduce and evaluate *V. anthelmintica* germplasm. The objective was to develop new varieties suited to American agriculture. In parallel, another program was initiated to conduct utilization research on the oil and its components.

VERNONIA ANTHELMINTICA OIL

Vernonia anthelmintica seed contains 23–31% oil with 68–75% vernolic acid (Princen, 1979). The best oil yields were obtained from mature seed. Commercial seed-cleaning equipment was used to remove lightweight, low-oil, immature seed (Krewson et al., 1965).

In undamaged seed, vernolic acid (Fig. 1A) occurs in triglyceride form. The acid may be attached to each position of the glyceride structure (trivernolin) (Fig. 1B), or to two (for example, 1,3 divernolin) or to only one position (monovernolin).

TABLE 1. OXIRANE OXYGEN VALUES FOR *Vernonia anthelmintica* OIL AND OTHER PRODUCTS[a]

	%
Vernonia oil (crude)	3.71
Vernonia oil (refined)	4.26
Vernonia oil epoxidized (crude)	7.13
Vernonia oil epoxidized (refined)	7.35
Trivernolin (97.8%) pure	5.06
Trivernolin epoxidized (crude)	8.30
Trivernolin epoxidized (refined)	8.35
Epoxidized linseed oil	9.00
Epoxidized soybean oil	6.60

[a] Adapted from Krewson et al., 1964.

In *V. anthelmintica* oil the epoxy acid is primarily present as trivernolin (Krewson, 1968).

Epoxy oils of greatest value are those with higher oxirane contents. The best quality vernonia oil is one in which all of the epoxy acid is present as trivernolin. Because vernolic acid is also a monounsaturated fatty acid, the naturally occurring double bond (-C=C-) can be chemically epoxidized to a product of even higher oxirane content. Table 1 shows the oxirane values for *V. anthelmintica* oil, trivernolin, the corresponding epoxidized materials, and commercial epoxidized linseed and soybean oils. Vernonia seed contains an active lipase, which, when seed is crushed, rapidly hydrolyzes the triglycerides to form glyceryl esters and free fatty acids. Free acids contribute to processing problems, oil instability, and poor plastic properties, and therefore oil high in such acids is low in quality.

AGRONOMIC RESEARCH

Substantial agronomic research was devoted to *Vernonia anthelmintica* (Higgins, 1968; Higgins and White, 1968; Berry and Lessman, 1969a,b; Berry et al., 1970a,b; Massey, 1971; White and Bass, 1971; White and Earle, 1971; Lai and Lessman, 1974). The goal was to develop varieties suitable for cultivation in the United States. The germplasm base consisted of 9 accessions from India and Pakistan, where the plant is valued for its medicinal properties and is cultivated or allowed to persist in or around the borders of cultivated fields. Some accessions were collected from cultivated or semicultivated plants; others were market samples. Although the germplasm base was not as broad as desirable, there was substantial genetic diversity.

Agronomists developed improved lines with shorter stature, more uniform seed maturity, and higher oil content, but showed that yields were limited by poor seed retention. Plants branch diffusely and produce many flower heads, up to about 1.5 cm in diameter. But those formed first lose their seed before those formed later mature. While the total seed crop was heavy, it was not adaptable to mechanical harvest because seed did not mature uniformly.

UTILIZATION RESEARCH

Vernonia anthelmintica oil, trivernolin, and salts of vernolic acid greatly improved heat and light stability of plasticized polyvinyl chloride (PVC) and were equal to or better than products used commercially (Riser et al., 1962).

Sesquiterpene lactones were isolated from more than 70 species of *Vernonia* during chemical evaluation of the genus (Bohlmann et al., 1981a,b). Some of the lactones were found to have antitumor and other pharmacological activity; vernolepin, cytotoxic to KB cells in vitro, was isolated from the leaves of the stengelioid *V. hymenolepis* A. Rich. (Kupchan et al., 1968, 1969a) and from the fruit of *V. amygdalina* Del. (Laekeman et al., 1983). Other components with tumor inhibitory activity were isolated from *V. amygdalina* (Kupchan et al., 1969b). Species from which other sesquiterpene lactones were isolated and characterized include: *V. anthelmintica* (Asaka et al., 1977), *V. colorata* (Willd.) Drake (Toubiana and Gaudemer, 1967); *V. lilacina* DC., *V. arkansana* DC., *V. lanuginosa* Gardn., *V. polyanthes* (Spreng.) Less., *V. fagifolia* Gardn., *V. chinensis* (Lam.) Less., *V. alvimii* H. Robinson (Bohlmann et al., 1981a); and *V. profuga* DeNot. (Bohlmann et al., 1981b). What role such toxic materials might play in feeding defatted seed meal to animals is unknown but must be considered.

Princen (1982) suggested that a natural epoxy oil source, such as *V. galamensis*, could make a significant contribution toward supplying the 45–68 million kg of epoxy oils used annually in the United States, products valued at $100,000,000. Perhaps a realistic starting point would be 4,000 ha of vernonia to provide a new raw material source for the plastics and coatings industries. The recent research on *V. galamensis* oil is only a beginning; further research should identify other uses that will increase this hypothetical production level.

PLANT EXPLORATION FOR VERNONIA GERMPLASM

Since *V. anthelmintica* belongs to *Vernonia* section Stengelia, all other species of which are African, exploration was undertaken in Africa by C. E. Smith, Jr., December 1966–March 1967 (Smith, 1971). Smith collected stengelioid and other vernonias in Ethiopia, Kenya, Uganda, Tanzania, and South Africa. This exploration was undertaken to broaden the germplasm base when it became evident little success was likely in developing a variety of *V. anthelmintica* as a new crop for the United States. Smith collected seed for analysis in eastern Africa but was too early to collect seed in southern Africa; subsequently collaborators there supplied seed from populations he located.

Some of these seed samples were analyzed for oil and vernolic acid; others, too small for analysis, were increased in Puerto Rico and subsequently analyzed. On the whole, the African stengelioid collections were not impressive. The best was *V. lasiopus* O. Hoffm. seed from western Uganda with 20.5–22.2% oil containing 75.2–81.3% vernolic acid (*Smith 4608, 4624; Smith, Wood, & Perdue 4612; Smith & Wood 4627;* all K, US).

Smith collected 5 lots of seed in the Kenya highlands from nonstengelioid plants then identified as *V. afromontana* R. E. Fries, but now recognized as subspecies of *V. galamensis* (Gilbert, 1986) (*Smith & Magogo 4570* = subsp. *nairobensis* M. Gilbert, *Smith & Magogo 4585 & 4591* = subsp. *gibbosa* M. Gilbert, *Smith & Njoroge 4640 & 4644* = subsp. *afromontana* (R. E. Fries) M. Gilbert, all K, US). Oil yield was up to 29.7%; vernolic acid yield was up to 78.2% of the oil.

Prior to the Smith exploration, R. E. Perdue, Jr., visited Ethiopia on another mission. Forearmed with knowledge of developing interest in stengelioid vernonias he collected seed of several species. In December 1964, at the height of

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Fig. 2. *Vernonia galamensis* ssp. *galamensis* var. *ethiopica*. Voucher specimen (US) for the initial seed collection in Ethiopia (*Perdue 6333*) (× ⅔). The 3 achenes (upper left) were removed from the uppermost flower head.

the dry season he encountered an interesting nonstengelioid vernonia (*Perdue 6333*, NA) in an arid area of eastern Ethiopia, 7 km southeast of Harar, elevation about 1,740 m (Lat 9°17′N, Long 42°11′E). Plants were fully mature (Fig. 2); most stems were dry, brown, and leafless. Seed retention was impressive. Dead-ripe achenes were resting in "cups" formed by involucral bracts, which had closed almost completely at their tips. He collected 280 g of clean fully mature seed.

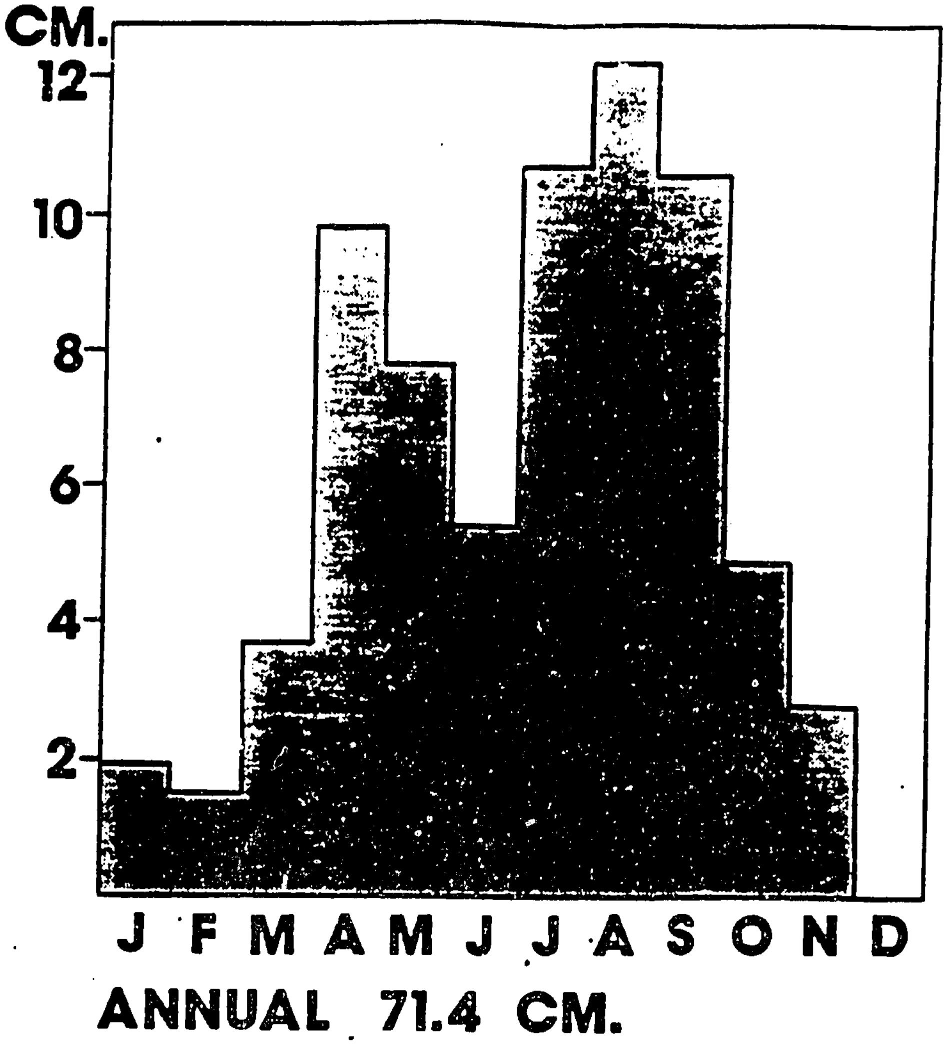


Fig. 3. Monthly rainfall distribution at Funyan Bira, Ethiopia, adapted from Wernstedt, 1972.

completely free of debris, from a population about 3.3 m^2. Stems were cut near ground level and seed emptied on a cotton throw cloth.

Fig. 3 shows rainfall distribution at Funyan Bira, the nearest weather station for which monthly data are available (Wernstedt, 1972). Funyan Bira, elevation 2,049 m, is about 27 km east of the field site, which is lower and drier. This rainfall pattern is characteristic of the area.

In view of the low annual rainfall (<72 cm) at a latitude of about 9½°, this is a very stressful environment, even at 1,740 m above sea level. Rainfall sufficient for seed germination would not fall until the beginning of the rainy season the following March or April. It appears that natural selection has favored a plant that will not shed its seed at maturity, but one that will retain its seed until rainfall is sufficient for germination and establishment of a new generation.

This collection was identified as *V. pauciflora* (Willd.) Less., now known as *V. galamensis* ssp. *galamensis* var. *ethiopica* M. Gilbert (Gilbert, 1986). The seed contained 41.9% oil with 72.6% vernolic acid, substantially better than any selections of *V. anthelmintica*, which at best contain 31% oil with 75% epoxy acid (Princen, 1979). This unimproved germplasm contained about 30% more vernolic acid than the best improved varieties of *V. anthelmintica*.

More recently one additional small sample of *V. galamensis* seed was obtained from The Gambia in West Africa. It is now being increased.

VERNONIA GALAMENSIS: BOTANY

Description

Herbaceous, usually annual (Fig. 4), rarely persisting for more than one growing season; varying from small ephemerals 20 cm tall with a single flower head to robust rather diffusely branching somewhat shrubby plants to 5 m tall with many flower heads; stems never branching from the base, branching only after the first flower head is formed; the inflorescence consisting of a terminal flower head with lateral flower heads from the uppermost axils, subsequently, if moisture is sufficient for continued growth, the lateral branches of the inflorescence elongating and branching again to produce secondary inflorescences overtopping the first formed inflorescence. Leaves alternate, sessile, membraneous, 0.6–5.0 cm wide, up to 25 cm long, acuminate at the tip, cuneate at the base, margins toothed, surface puberulous to pilose. Characters otherwise as typical of *Vernonia*, separated by Gilbert (1986) into 6 subspecies, primarily by characters of the phyllaries.

Taxonomy

Jones (1981) developed a synoptic classification of Old World *Vernonia* that relied strongly on pollen characteristics, but reflected phytochemistry, cytotaxonomy, cytogenetics, and morphology to the extent such information was available. *V. galamensis* belongs to subgenus Orbisvestus (which is restricted to the Old World tropics and subtropics), section Orbisvestus, and is the type species of subsection Centrapalus. Species of this subsection are coarse annuals to perennial herbs or semishrubs of grasslands and successional habitats from south of the Sahara into South Africa. They can be distinguished from other African species with similar pollen by their brownish pubescent achenes.

Wild (1978) studied *Vernonia* of the Flora Zambesiaca area and first recognized the subject species as *V. pauciflora* (Willd.) Less. Subsequently, he (Wild, 1978, errata) accepted *V. galamensis* (Cass.) Less. as the correct name for this species.

More recently, prompted by the new interest in *V. galamensis* as a potential new vernolic acid source, Gilbert (1986) studied this species in greater depth. He concluded that within the complex formerly called *V. galamensis*, a locally endemic population in northern Tanzania should be segregated as a new species, *V. filisquama* M. Gilbert, and plants earlier recognized as *V. afromontana* R. E. Fries are better considered as a subspecies of *V. galamensis*. According to Gilbert's concept of *V. galamensis*, this widely distributed species includes 6 subspecies, one of which includes 4 varieties:

. ssp. *galamensis*
  a. var. *galamensis*
  b. var. *petitiana* (A. Rich.) M. Gilbert
  c. var. *australis* M. Gilbert
  d. var. *ethiopica* M. Gilbert
2. ssp. *nairobensis* M. Gilbert
3. ssp. *lushotoensis* M. Gilbert
4. ssp. *mutomoensis* M. Gilbert
5. ssp. *afromontana* (R. E. Fries) M. Gilbert
6. ssp. *gibbosa* M. Gilbert

Fig. 4. *Vernonia galamensis* ssp. *galamensis* var. *ethiopica*. From specimen collected by L. Bates at Kericho, Kenya, January 19, 1978, NA. Habit, including root $\times \frac{2}{3}$, single flower head (bottom) $\times \frac{9}{10}$, achenes and flowers × 4.

Distribution

Fig. 5 and 6 are based on specimens at Kew Herbarium and the East African Herbarium (EA), Nairobi, Kenya. Fig. 5 shows distribution of *V. filisquama* and the 4 subspecies of *V. galamensis*; Fig. 6 shows distribution of the other subspecies. It is evident from Gilbert's treatment that this widely distributed species is highly diverse and its center of diversity is in East Africa.

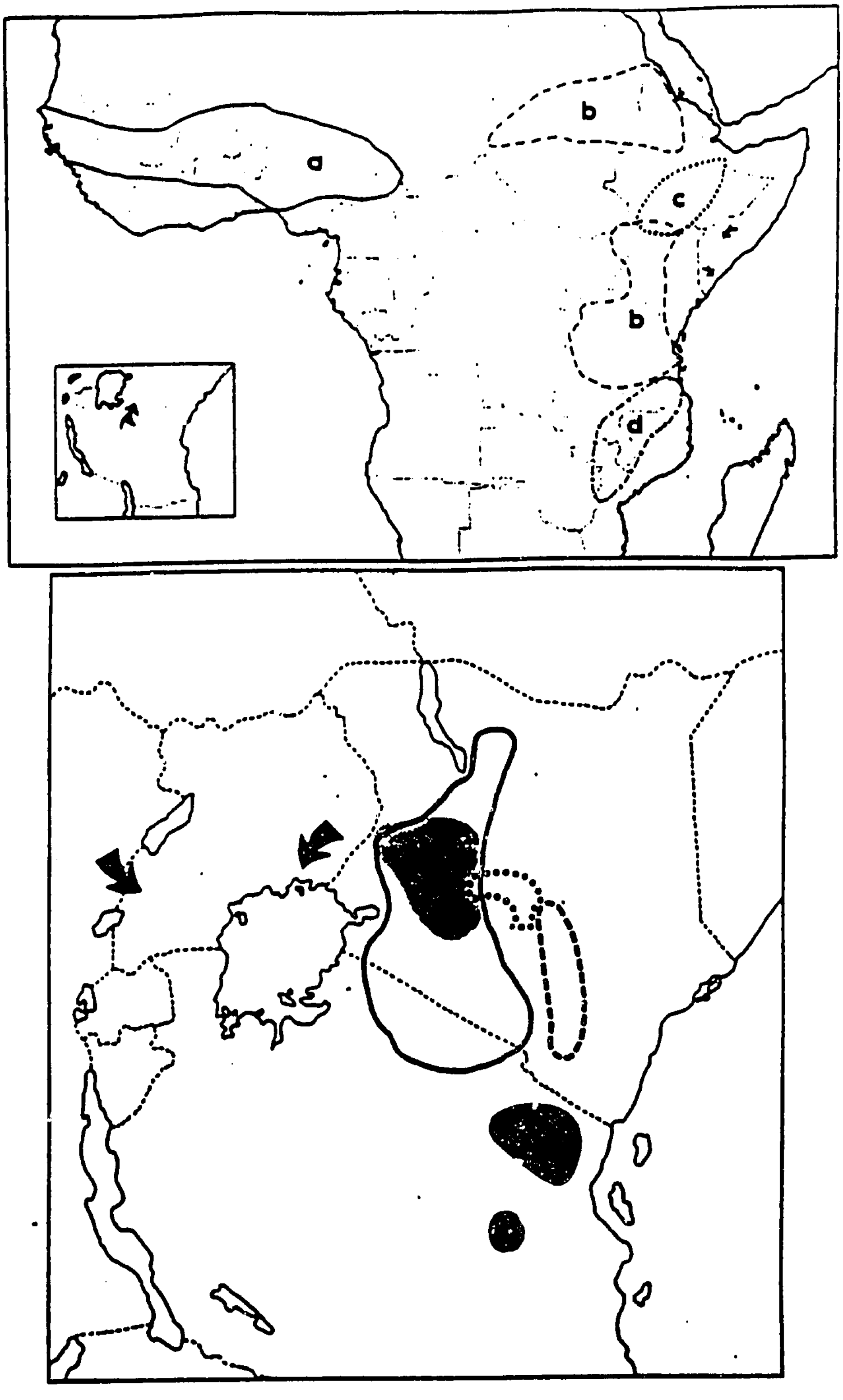
Within ssp. *galamensis* Gilbert defines 4 varieties that seem fairly well separated geographically and/or ecologically. The West African var. *galamensis* (west of 14°E) is found only in areas of lower rainfall. Var. *petitiana* is in Ethiopia, Kenya, Somalia, Sudan, Tanzania, and Uganda; var. *australis* is distributed from southern Tanzania through Mozambique to eastern Zimbabwe, each reaching about 19° distant from the equator. Var. *ethiopica* occurs in southern and eastern Ethiopia at elevations of 1,250–2,075 m, on the whole at higher elevations than those recorded for var. *petitiana* (mostly 750–1,500 m).

Ssp. *nairobensis* is a common plant in the uplands (1,300–2,250 m) of Kenya and northern Tanzania, a ruderal of forest margins and clearings. Ssp. *gibbosa* is endemic to a small area northeast of Mt. Kenya. Ssp. *afromontana*, one of the most distinct segregates, occurs in montane forests or former forest areas (1,900–2,400 m) of central and western Kenya, often under trees. Ssp. *mutomoensis* is endemic to the Ukambani-Taita area of Kenya where it is largely associated with basement complex inselbergs at substantially lower elevations (700–1,150 m). While ssp. *lushotoensis* does occur at isolated points in Uganda (3 records), it is by far most common as a ruderal in wet forest areas of eastern Tanzania, primarily in Lushoto District in the Usambara Mts.

The *V. galamensis* segregates occur in areas with annual rainfall as low as 50 cm, occupied by *Acacia-Commiphora* bushland/woodland, to rich forested areas with annual rainfall of 185 cm, but no subspecies occurs through a large proportion of this ecological range. Ssp. *mutomoensis* and ssp. *galamensis* are restricted to drier habitats and avoid areas without a well-defined and severe dry season. Ssp. *nairobensis* and ssp. *gibbosa* occur in areas characterized by dry evergreen forest often dominated by *Brachylaena* or *Olea* with members of the Rutaceae, especially *Teclea*, *Vepris*, and *Calodendrum*, forming an important component. In these areas rainfall is bimodal but is distinctly higher and more reliable than in the areas occupied by *Acacia-Commiphora* bushland/woodland. Ssp. *afromontana* and ssp. *lushotoensis* occur in the areas of highest rainfall, which rarely have a prolonged dry period, and where the natural vegetation is tall forest rich in epiphytes. All the subspecies are restricted to rather open situations and are very much favored by disturbance. They are usually most conspicuous in ruderal situations and characteristically occur on porous well-drained soils.

VERNONIA GALAMENSIS: TRIAL PLANTINGS

Seed from the Perdue 1964 collection were planted at Experiment, Georgia. Plants grew to 1.2–1.5 m tall and produced a few flowers but no seed. Leaves were discolored and appeared diseased. Seed was subsequently increased in a greenhouse at Glenn Dale, Maryland. Plants flowered in November and seed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matured in December. At that time there was no interest in this species as a potential new crop for the United States.

In July 1975, Leonard Bates (pers. comm.), African Highlands Produce Company, Kericho, Kenya, planted seed, increased from that collected in Ethiopia.

Plants initially formed single unbranched stems and subsequently branched above, after terminal flower heads were formed. Seed was harvested in March 1976 and contained 40% oil with 80% vernolic acid, about the same as the original seed from Ethiopia. A much larger planting at Kericho was made in early July 1977; the crop was harvested in late February. Even though average annual rainfall at Kericho is 185 cm, almost 3 times that of the area of Ethiopia where seed was initially collected, there was no evidence of disease, insect, or other problems. No data on seed yield are available but it was substantial. Bates' success with the Kericho planting prompted new interest. He supplied substantial seed, source of the oil used to establish the value of this product in the manufacture of coatings (Carlson et al., 1981).

More recently, small plantings were established at Mombasa, Kenya (R. Haller, pers. comm.), Cayey, Puerto Rico (A. Sanders, pers. comm.), Isabela, Puerto Rico (F. Vazquez, pers. comm.), and at 5 locations in Jamaica (B. C. Akehurst, pers. comm.). The Mombasa and Cayey plantings produced substantial amounts of seed and there was no (Cayey) or minimal (Mombasa) evidence of disease, insect, or other problems. The Isabela and Jamaica plantings failed.

At Isabela, in 1982 and 1983, plants grew to a height of about 0.6 m, the leaves turned brown and the plants died. Specimens from the 1982 planting, including roots from which soil had been removed, were examined by specialists at Beltsville, MD, for evidence of insects, disease, and nematodes. None could be found. Additional specimens were obtained from the 1983 planting; these included balls of soil around the roots and these too showed no evidence of parasites or pathogens. Absence of insects, nematodes, or disease suggests failure was due to a physiological disorder probably associated with excessive soil moisture. The response in Jamaica was similar to that at Isabela; plants tended to die off, root rot was observed and a *Fusarium* was identified as the possible causative agent. At one Jamaica site, soil was "heavy clay"; soils at the other 4 were "medium textured silty to clay loams."

At most sites there was good seed germination. At none was seed retention comparable to that initially observed in the natural stand in Ethiopia.

In none of the successful plantings (2 at Kericho, 1 each at Mombasa, and Cayey) have plants developed as they did in Ethiopia, where the original germ-

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Fig. 5–6. Fig. 5. Distribution of *Vernonia filisquama* and *V. galamensis* subsp. *galamensis*. *V. filisquama* is recorded from several locations in northern Tanzania (arrow, box, lower left). *V. galamensis* subsp. *galamensis* includes 4 varieties distributed from West Africa, east to Sudan and Ethiopia, then south to Zimbabwe and Mozambique. a. var. *galamensis*. b. var. *petitiana* (arrows show 2 isolated records in Somalia). c. var. *ethiopica*. d. var. *australis*. Fig. 6. Distribution of 5 subspecies of *Vernonia galamensis* found only in East Africa (Uganda, Kenya, and Tanzania), the center of diversity of this species: subsp. *nairobensis* (solid line), subsp. *afromontana* (stippled), subsp. *gibbosa* (dotted line), subsp. *mutomoensis* (dashed line), subsp. *lushotoensis* (black; arrows show isolated collections in Uganda).

plasm was collected. In contrast to Ethiopia, where plants produced only a few flower heads that matured uniformly and retained most seed produced, plants grown at Cayey, Kericho, and Mombasa produced many flower heads that did not mature uniformly. This was most likely due to the prolonged growing season in response to the higher precipitation characteristic of Kericho, Mombasa, and Cayey, which encouraged development of secondary inflorescences.

On January 20, 1984, Perdue observed a small *V. galamensis* planting at the Botanic Garden, Harare, Zimbabwe, from seed increased from the original collection in Ethiopia. Seed was sown under glass June 28, 1983 (M. Leppard, pers. comm.). Plants 30 cm tall were transplanted September 15. The first flower heads appeared September 19. In January, plants were luxurious and profusely branching, about 1 m tall, with many immature flower heads terminating the branches. But on each plant, about 30 cm above ground level, there was a fully mature flower head and other fully mature flower heads were at levels 45–60 cm above ground level. Seed was dead ripe. Involucral bracts had spread completely open and were beginning to reflex but no seed had been shed. The plants had been overwatered and were growing on the site of a former compost pile. The luxurious growth seemed due to excessive moisture and fertility. Had these plants been subject to severe moisture stress soon after initial flowering, conditions somewhat like those illustrated by Fig. 3, these plants would have produced few flower heads, all of which would have matured and retained their seed. Here, seed retention by the first-formed flower heads was striking.

Good seed retention was also observed in 2 small plantings in 1983 near Mufindi, Tanzania (T. C. E. Congdon, pers. comm.). The plants grew well at Lugoda (tea) Estate where rainfall is generous but there is a 2-mo, more-or-less rain-free period, the pattern that seems essential to good seed retention.

CONCLUSIONS

While much remains to be learned about *V. galamensis* it seems to offer good prospects as a new crop for semiarid areas of the tropics and subtropics. Judging from the analysis of seed from the natural stand in Ethiopia, confirmed by analysis of seed produced when the Ethiopian germplasm was grown in Kenya, seed is substantially superior to that of *V. anthelmintica* as a source of oil and vernolic acid. In the limited trial plantings there was no clear evidence of insect, disease, or other formidable problems. Failures so far seem most likely due to unsuitable environments with excessive moisture and/or poorly drained soils. The good natural seed retention observed initially in Ethiopia, and subsequently in Tanzania and Zimbabwe, is encouraging as is the observation of J. H. Seyani, University of Malawi (pers. comm.): "... some herbarium specimens of *V. galamensis* with mature capitula seem to retain their achenes very well ... this must be one of the characteristics of the population in the wild."

The natural distribution of *V. galamensis* in Africa and other observations reported here suggest that development of this species as a new crop should be focused on areas where rainfall is concentrated during a period of 4, or at most 5 mo, followed by 1 or 2 mo in which rainfall is nil or nearly so. Rainfall pattern is probably more important than total amount. The ideal pattern is likely to be one similar to that at Funyan Bira, Ethiopia (Fig. 3). There must be sufficient rainfall to establish good stands and bring the first flower heads on each stem to maturity, but not enough to prolong growth so the plant will produce many secondary inflorescences. Such additional development leads to lack of uniformity in seed maturity and subsequent dispersal of mature seed during showers.

The probability is good that an even better source of oil and vernolic acid can be identified within *V. galamensis*, if a broad diversity of the available germplasm of this species is acquired. Prospects are good that a superior variety can be developed with higher oil yield and higher percent of trivernolin in the oil.

Plant exploration to acquire additional germplasm was undertaken in Africa in 1984 by Agricultural Research Service botanists G. M. Christenson (Malawi and Zambia) and S. M. Saufferer (Kenya and Tanzania). Since so few African species have been tested for oil and vernolic acid yields, seed of other species was also collected to determine if sources superior to *V. galamensis* can be identified. In addition, further collecting of seed of vernonia species was undertaken by botanists and other workers in Zimbabwe. All available germplasm will be grown for further evaluation and seed increase at research stations of the Department of Research and Specialist Services, Ministry of Agriculture, Zimbabwe in 1984–1985.

Utilization research has shown *V. galamensis* oil may have a place in the coatings industry. Further investigation should extend the market. A promising area for continuing research is that of Sperling and Manson (1983) who have used vernonia and other epoxy oils to form interpenetrating polymer networks with polystyrene to produce elastomers and plastics with properties suitable for many uses.

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Vernonia galamensis Seed Oil: A New Source for Epoxy Coatings

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ABSTRACT

A native African plant, *Vernonia galamensis*, is an excellent source of epoxy acid-containing triglyceride oil. The seed contains 40-42% oil, and the vernolic (*cis*-12,13-epoxy-*cis*-9-octadecenoic) acid content of the oil falls in the range 72-78%. Processing conditions have been explored for cleaning, tempering, and flaking the seed; efficient extraction and recovery of the crude oil; and subsequent oil refining steps. As is characteristic of *Vernonia* species, rapid lipolytic activity in crushed *V. galamensis* seeds can lead to high free fatty acid levels in subsequently extracted oil if proper precautions are not taken in the processing steps. The film-forming properties of *V. galamensis* oil were evaluated by spreading the oil on steel panels, which were then baked for various times and temperatures with and without added metal driers. In preliminary evaluations, all coatings withstood direct and reverse impact as well as severe bending and cutting actions. These results are indicative of excellent flexibility, resistance to chipping, adhesion to substrate, and cohesive film properties. Resistance to mineral acid, alkali, detergent, and solvent was judged excellent.

INTRODUCTION

Several review articles (1-3) and numerous other papers (4-16) have discussed the characterization and possible uses of naturally occurring epoxy oils since the discovery of vernolic acid (*cis*-12,13-epoxy-*cis*-9-octadecenoic acid) in

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Vernonia anthelmintica seed oil (17). Many other sources of vernolic acid and several other epoxy acids have been identified, but only species of the families *Compositae* and *Euphorbiaceae* contain relatively high levels (above 40%) of epoxy acids (2,7,15). *Vernonia* species are members of the family *Compositae*, and may be annual or perennial herbs, small to large shrubs, woody scramblers and climbers, or rarely, small trees. This very large genus of tropical and warm temperate plants is found in America, Africa, Madagascar, and Asia. *V. galamensis* (Cass.) Less., previously referred to as *V. pauciflora* (Willd.) Less. (18), is an annual herb occurring as a weed of cultivation or in woodlands of E. Zimbabwe, S. Malawi, N. Mozambique, Senegal, Ethiopia, Eritrea, Tanganyika, and throughout W. Tropical Africa. With a blue corolla, the flower head of *V. galamensis* is 3-4 cm wide and hemispheric with involucral bracts which tend to retain the maturing seed within the head. Seeds are dark brown to black, 5-6 mm long X 1.5 mm wide with silky hairs, *ca.* 0.5 mm long. Each bristle in the tuft or pappus at the large end of the seed is 7-8 mm long and is covered with minute barbed setae *ca.* 0.1 mm long (Fig. 1A). Since the seed contains *ca.* 42% oil, and vernolic acid constitutes *ca.* 78% of the oil by weight, *V. galamensis* is one of the richest sources of this natural epoxy acid. Early indications are that *V. galamensis* has greater promise agronomically than other potential epoxy oil sources such as *V. anthelmintica*, *Stokesia laevis*, and *Euphorbia* species (1-2). In this paper, we present results of our processing studies on *V. galamensis* seed and our preliminary evaluation of the oil as a coatings raw material.

MATERIALS AND METHODS

Vernonia galamensis seed was grown in Kenya and Puerto Rico through the efforts and interest of Mr. L. Bates of Nairobi, Kenya, and Mr. A. Sanders of London, England. Virtually all work reported here was performed on the Kenya seed. As received, the seed was relatively clean except for fibrous material associated with the seed, such as pappi or setae in both free (Fig. 1C) and seed-intact (Fig. 1A) forms. Use of standard screens and sieves removed some free fiber and dust and tended to partially fractionate the seed according to size, but pappi and setae remained attached to a large proportion of the seed. Similarly, a Bates Laboratory Aspirator removed loose debris but was of little value in "dehairing" the seed. However, after tempering (see below), the seed was essentially free of pappi and most of

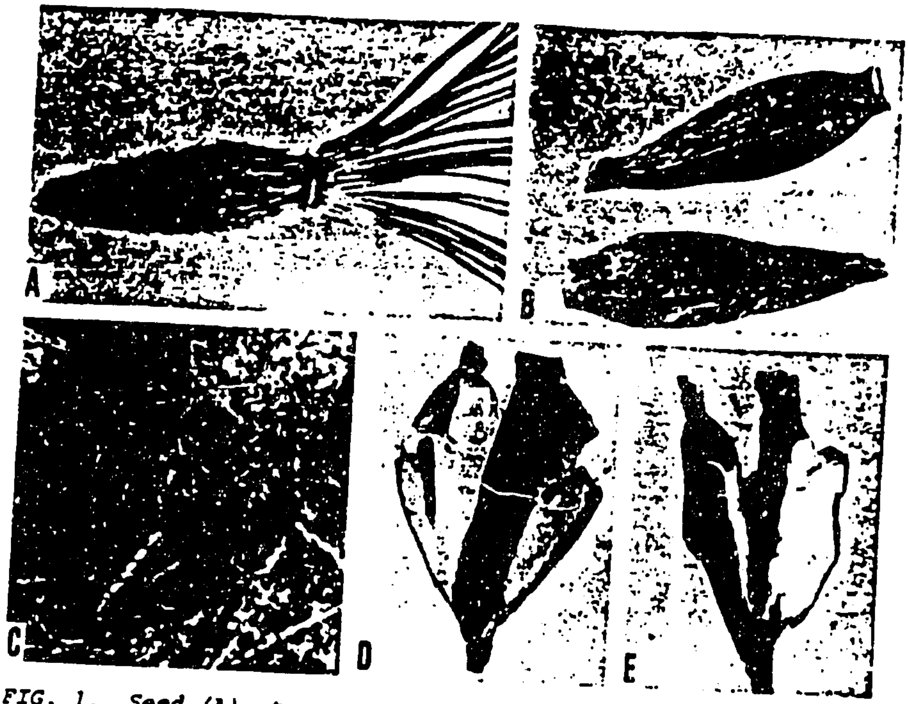

FIG. 1. Seed (A), tempered seed (B), fibers (C), full-fat flake (D), and defatted flake (E) of V. galamensis.

the setae (Fig. 1B) permitting separation by screening or aspiration.

ANALYSES

Analyses following Official AOCS Methods (19) included: moisture (Ac 2-41); oil (Ac 3-44); free fatty acid (FFA) (Ca 5a-40); nitrogen (Ba 4-38) and crude protein (N X 6.25); oxirane oxygen using HBr at 25 C (Cd 9-57); Gardner color (Td 1a-64); ash (Ba 5-49); and crude fiber (Ba 6-61). Oil viscosity was determined at 25 C with a Brookfield Model LVT Synchro-Lectric Viscometer (Brookfield Engineering Laboratories, Stouton, Massachusetts). Amino acids were determined on defatted flake meal by the methods of Benson and Patterson (20) and Cavins and Friedman (21). Infrared (IR) spectra of 10% oil solutions in CCl_4 were recorded on Perkin Elmer 137 or 337 spectrophotometers. Thin-layer chromatographic analyses (TLC) were performed on commercial precoated plates (0.25 mm silica gel 60 F-254, E. Merck, Darmstadt, Germany). Developing solvent was hexane:diethyl ether (70:30 or 60:40, v/v), except when FFA were of particular interest in which case hexane:diethyl ether:acetic acid mixtures were used (70:30:1 or 60:40:1). Visualization was by charring at 130 C with sulfuric:chromic acid solution. Epoxy groups in oil components, FFA, or esters were revealed on TLC plates (without fluorescent indicators) by the picric acid technique (22). Direct chromatographic comparisons were made with related *V. anthelmintica* oil, FFA, or esters. Fatty acid methyl esters were prepared from the oil by two procedures: (a) transesterification with 0.276 M sodium methoxide in methanol, which leaves the epoxy groups intact, and (b) saponification in 0.5 N NaOH in methanol followed by reaction with 10% BF_3 in methanol, which provides methyl esters as hydroxy-methoxy derivatives of the epoxy group (23). Gas chromatography (GC) of the methyl esters was carried out isothermally at 185 C on glass columns packed with 5% LAC-2-R 446 and 5% Apiezon L (14,15). Column chromatography was run on silica gel 60 (70-230 mesh; E. Merck) packed in a 2.8 X 50 cm glass column. Oil (1 g) components were separated on 110 g silica gel by elution with hexane containing increasing amounts of diethyl ether. Esters (1 g) prepared with sodium methoxide were similarly separated into normal and epoxy types on 110 g silica gel with hexane:diethyl ether (90:10). Esters (1 g) prepared by the BF_3 procedure were fractionated into normal and hydroxy-methoxy types on 50 g silica gel by elution with hexane:diethyl ether mixtures (incrementally from 90:10 to 50:50). Progress of these fractionations was monitored by TLC.

SEED TEMPERING (LIPASE INACTIVATION)

Seed (454 g) was tempered in the laboratory in a covered, 2-L, steam-jacketed, stainless steel (SS) beaker fitted with thermometer and variable speed stirrer. In the pilot plant, up to 10 kg of seed was tempered in a covered one cu-ft, steam-jacketed, double-ribbon, SS blender with variable speed drive (24,25). Seed temperatures were kept at 95-100 C, and seed moistures were adjusted upward from ambient (5%) to 15% during tempering by adding the required weight of water to the tempering units at appropriate times. Final seed moistures were 7-15% in the laboratory runs and consistently 14-15% in the pilot plant. All moist tempering periods were ca. 90 min. The initial laboratory run involved both a dry heat (0-60 min) and a moist heat (60-150 min) period during which seed samples were removed for moisture and oil analyses and for FFA checks of the oil. In all other runs, seed samples were taken only at the start and finish of the tempering periods. Tempered seed was air dried (4-7% moisture) overnight and then stored at *ca.* 5 C until needed.

SEED FLAKING

Tempered seed was flaked on a Wolf flaking mill with smooth-faced, 12 in. rolls set within the range 0.002-0.010 in. A setting of 0.002-0.003 in. gave whole-seed flakes of uniform thickness (Fig. 1D) when the seed moisture ranged from 5-9%. For analytical samples, flakes or whole seeds were ground in a laboratory Wiley Mill through 20 or 30 mesh screens.

OIL EXTRACTION

All extractions were with petroleum ether or commercial hexane. For analytical samples, Butt or soxhlet extractors were used (6 hr). Other laboratory extractions were carried out with 50, 500, and 3,000 g of flakes in percolation cones (glass or SS). Contact times for individual solvent fractions ranged from 15 min (50 g scale) to 18 hr. Solvent fractions were combined or kept separate depending on the purposes of the experiment. Cumulative solvent volumes ranged from 4-13 L/kg of flakes in these extractions. Pilot plant extractions were of two types--soxhlet and steep. The commercially designed SS soxhlet (Model SE-5, Artisan Industries Inc., Waltham, Massachusetts) was a cylinder with a steel plate dividing the two basic parts--an upper thimble (4-6 kg flakes with 8-12 L solvent) and a lower still pot (30-40 L capacity)--and distillate was fed from the condenser to the thimble *via* a side port opposite and level with the siphon take-off. Pot temperature during cycling was 67-68 C, and cycle times were only 7-15 min. Flakes were contained in a cheese cloth bag in the wire thimble basket. Soxhlet run <u>1</u> was monitored by removing extract aliquots (100 ml) from the still pot (after cycles 1-8, 18, 36, 51) and determining oil content gravimetrically. After eight cycles, 83% of the oil had been extracted; after 51 cycles, only 85% had been recovered so cycling was terminated and the run was completed with three cold steeps (2,2,66 hr) in the soxhlet thimble. Soxhlet run <u>2</u> was not monitored and was carried through 22 cycles (15 min) and eight cold steeps (1 1/2-17 hr duration).

The soxhlet thimble was used as a reservoir for steep extractions <u>1</u> and <u>2</u>, which were performed at 20-25 C. Flakes were contained in a cheesecloth bag. Six 7.6 L portions of hexane were used in each steep extraction with contact times each of 60 min (run <u>1</u>) and 30 min (run <u>2</u>). In both runs, each fraction was collected separately, and an aliquot (50 mL) was evaporated to estimate oil recovery as a function of cumulative solvent volume. Pilot plant extracts were concentrated at *ca*. 40 C in a SS and glass, single effect, natural circulation, rising film evaporator (Precision Scientific Co.) (26). Final solvent stripping was carried out in a rotary evaporator at 60 C and 10-20 mm Hg for 1 hr. Flakes were desolventized to the atmosphere in a hood over 48 hr.

OIL REFINING

Crude oil was refined with activated charcoal (char, Darco G-60) at levels of 2, 5, and 8% by weight. For example, oil (481.7 g, from percolation extraction of 1.27 kg tempered flakes) was mixed with char (9.6 g, 2%) at 60 C, 10 mm Hg, for 1 hr. Decolorized oil was isolated by hot filtration (steam-jacketed Buchner funnel) through a bed of Celite filter aid (405.8 g, 84.3% recovery). In a second example, 119 g char-refined oil was recovered from 137 g of crude oil (87% recovery).

Crude oil (125 g, four replicates) was degummed by stirring with 2.5 g (three samples) or 5 g (one sample) of distilled water at 50 C for 1 hr followed by centrifugation at 2,800 rpm for 2-3 hr. Gum and oil were separated and the oil was dried at 60 C and 10 mm Hg on a rotary evaporator (121.9 ± 0.6 g, 97.6% recovery). One sample of this oil was then treated at 60 C and 10 mm Hg for 90 min with char (10 g, 8.2%) and centrifuged, and the oil was isolated (94.9 g, 78.1% recovery). For comparison, a sample of *V. anthelmintica* oil (125 g) containing 13% FFA was degummed (4% water) (118.5 g, 94.8% recovery), treated with char (2%) at 60 C, 15 mm Hg, 1 hr, and centrifuged, and the oil was isolated (110.1 g, 93% recovery).

Degummed oil (120 g, three replicates) was alkali refined at 40 C by adding 1.8 mL (two samples) or 3.6 mL (one sample) of 2 N NaOH (1.2 or 2.4% by weight) to the oil with stirring for 30 min. Troublesome emulsions resulted which were ultimately broken by alternately centrifuging (2,800 rpm) and washing with saturated NaCl solution. Oil was dried 1 hr on a rotary evaporator at 60 C, 10 mm Hg (100.7 ± 0.6 g, 83.3% recovery).

Degummed and alkali-refined oil (95.6 g) was bleached with AOCS neutral bleaching earth (1 g) by mixing on a rotary evaporator at 60 C and 15 mm Hg for 30 min, followed by centrifuging (2,800 rpm) to separate the oil from the earth (93.3 g, 97.6% recovery). Degummed and alkali-refined oil (101 g) was also simultaneously bleached and char-treated by mixing with AOCS neutral earth (1 g) and char

(2 g) at 60 C and 15 mm Hg pressure for 45 min, centrifuging (2,800 rpm) and separating the oil (93.9 g, 92.9% recovery).

PREPARATION AND PROPERTIES OF COATINGS

Char-treated *Vernonia* oil (3.58% oxirane, 1.35% FFA), with or without metallic driers (Co, Mn, Zr; 0.01-0.20% by weight), was spread on cold rolled steel type S Q-panels (The Q-Panel Co., Cleveland, Ohio, 4 X 8 X 0.032 in.) in a film initially 0.004 in. thick. Panels were then baked in an oven at temperatures of 150, 175, or 200 C (± 5) for periods from 10 to 120 min.

Coated panels were evaluated by ASTM methods (27) for hardness with a Sward Hardness Rocker (D2134-66), elongation with a conical mandrel (D522-60), and deformation at 80 and 160 in.-lb direct and reverse impact (D2794-69).

Chemical resistance of the coatings to alkali, acid, and solvent was evaluated visually with time by covered spot tests (D1308-57), by placing 1% Spic and Span solution (pH 9.9), 5% aqueous HCl, and xylene, respectively, at different locations on the panels. Discoloration, changes in gloss, blistering, softening, swelling, and loss of adhesion were noted.

RESULTS AND DISCUSSION

The "hairiness" of the seeds (Fig. 1A) presents special problems of bulk in the handling and processing steps. In addition, the fibrous debris (Fig. 1C) is a nuisance and can be an irritant at all stages. Once the seed is "dehaired," which occurs readily in the tempering stage to be discussed below, the seed can be nicely flaked in preparation for oil extraction. A second special consideration in processing *V. galamensis* seed is FFA levels in the extracted oil. High lipolytic enzyme activity is present in many seeds, and especially in epoxy acid-containing oil seeds, steps must be taken to destroy this activity or large amounts of FFA may be formed once the seed is crushed (1,5,6,9,28,29).

CONTROLLING LIPASE ACTIVITY

Our initial experiment was designed to tell us what temperature/time/moisture conditions were needed to inactivate this enzyme system in whole *V. galamensis* seed. Figure 2 shows profiles for seed temperature, moisture, and oil obtained in the laboratory with 454 g of whole *Vernonia* seed during 60 min of dry heat followed by 90 min of moist heat after water had been added to the system. Seed samples were removed at regular intervals for the moisture and oil analyses. Extractable oil rose from 38% in the ambient seed to 42% in the fully tempered seed (155 min) and dropped only slightly when the seed was dry heated at 130 C for an additional 120 min. Although the seed moisture was raised only to 8% in this experiment, this appeared to be sufficient at 99 C to inactivate lipid hydrolyzing enzyme(s) in the whole seed. This was determined quickly by examining the oil extracted from the seed aliquots for FFA using IR spectroscopy and TLC.

Figure 3A-C shows IR spectra for oil extracted from 0, 60, and 120 min seed aliquots representing ambient, dry-heated, and moist tempered seed, respectively. Significant hydroxyl (2.8-4 μm) and carbonyl (5.80 μm) absorptions due to FFA carboxyl groups are observed in the oil extracted from both ambient (Fig. 3A; FFA ∿ 15-20%) and dry-heated seed (Fig. 3B; FFA ∿ 10-15%). Not surprisingly, lipolytic

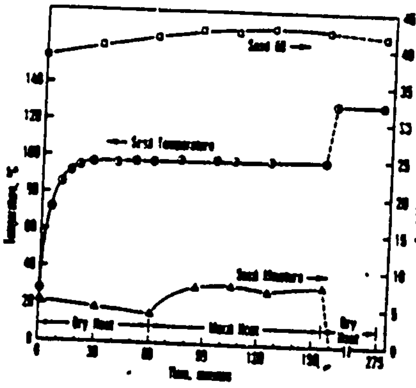

FIG. 2. Temperature, moisture and oil profiles during tempering of V. galamensis seeds.

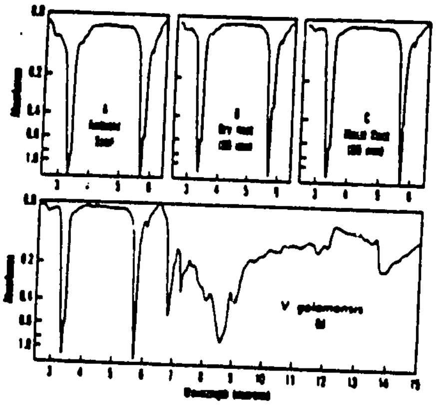

FIG. 3. IR spectra of V. galamensis oil extracted from seed aliquots removed during tempering run shown in Fig. 2: (A) ambient seed, (B) dry-heated seed, (C) moist-tempered seed. Lower curve = oil extracted from bulk seed at end of run.

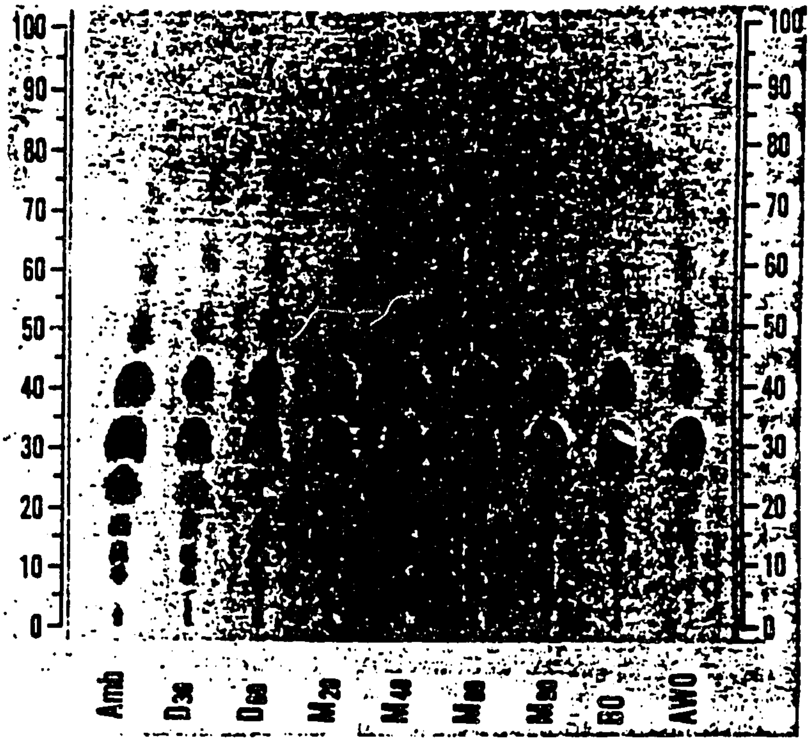

FIG. 4. TLC of V. galamensis *oil extracted from seed aliquots removed during tempering run shown in Fig. 2: Amb = ambient seed; D_{30}, D_{60} = 30 and 60 min dry-heated seed; M_{20}→M_{90} = 20, 40, 60, 90 min moist-heated seed; BO = oil from bulk tempered seed; AWO = alkali washed oil.*

activity was only partially reduced by the dry heat treatment (28), which also lowered the seed moisture to 3.5%. Moist heat, however, greatly reduced lipolytic activity within 20 min, and FFA absorptions at 2.8-4 µm and 5.80 µm are absent from the IR spectra of oil extracted from 40, 60 (Fig. 3C), and 90 min moist tempered seed (moisture 8%).

TLC analysis of oil from the various tempered seed aliquots was also instructive (Fig. 4). Oil from ambient seed (Amb) and from dry heated seed aliquots (D_{30}, D_{60}) contain FFA in the form of vernolic acid (at Rf 0.2-0.25). Moist tempered seed oil (M_{20}, M_{40}, M_{60}, and M_{90}) and the oil from the bulk sample of tempered seed (BO) contained much less free vernolic acid. For comparison, the right hand lane is oil that had been washed with dilute alkali (AWO) to remove FFA. In descending order, the major spots on the chromatogram are (Rf): normal triglycerides (0.6), monovernoyl triglycerides (0.5), divernoyl triglycerides (0.4), trivernolin (0.3), and vernolic acid (0.25). In this initial experiment, the bulk oil (lower curve of Fig. 3), obtained from the fully tempered seed, contained only 1.3% FFA and exhibited typical epoxy absorptions at 11.8 and 12.1 µm (30).

From these results, we felt confident that a seed moisture above 8% and a tempering temperature of 95-100 C for 60-90 min would suffice to inactivate lipid hydrolyzing enzyme(s) in the whole seed. Three similar 454 g runs were made wherein the dry heat periods were eliminated and sufficient moisture was added to the system prior to the heating cycle to give a final moisture content of 8-15% in the tempered seed. Tempered and air-dried seed was then flaked and extracted with hexane. Table 1 summarizes the results of the four laboratory runs. Average oil recovery was 39.7% or 95.7% of theory (41.5%). IR and TLC analyses of oil from runs 2, 3, and 4 indicated very low FFA levels, and FFA content of the composite oil from the four runs was 0.78%. Of the flake input, an average of 97.1% was recovered as meal and oil after extraction.

In the pilot plant scale-up, tempering was accomplished by adding sufficient water to preheated seed (95 C) to raise the seed moisture to 14% over 90 min of tempering. Tempered seed was air-dried and flaked. Oil was extracted from 2.8 kg of these flakes in a percolation cylinder by collecting 3 L of hexane from each of five percolation extractions of the flakes. Oil was isolated separately from each extraction. Oil recovery and vernolic acid content of the oil

TABLE 1

Flake and Oil Recovery in Laboratory Runs

Run no.	Hexane, L	Flakes in, g	Flakes out, g	Oil out g	Oil out % (db)	Oil + flake recovery, %
1	5.5	365	211	137	39.4	95.3
2	4.5	432	249	159	38.4	94.3
3	5.1	417	256	158	39.7	99.1
4	6.0	422	254	165	41.1	99.4
	21.1	1,636	970	619	39.7[a]	97.1

[a] 95.7% Oil recovery; theory = 41.50% oil (dry weight basis).

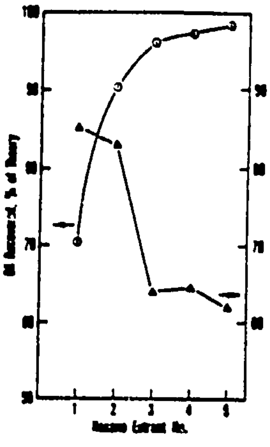

FIG. 5. Oil recovery and its vernolic acid content (GLC) in sequential hexane extracts.

fractions are shown in Figure 5 (see also Fig. 6, curve LLP). Note that 70% of the oil was recovered in the initial hexane fraction while only 1% was recovered in each of the last two fractions. Greater than 98% oil recovery was achieved with only 0.42% FFA in the oil, and the spent flakes contained only 0.91% residual oil. Vernolic acid appears to be enriched in the first two fractions relative to the latter three extracts, implying that initially triglycerides rich in vernolic acid are preferentially extracted. Thus, a simple means may be available for obtaining oil with higher epoxy content than the whole *V. galamensis* oil.

OIL EXTRACTION AND RECOVERY

With no apparent problems with lipolytic enzyme inactivation or FFA build-up in recovered oil, larger scale extraction was attempted next. Two methods of oil extraction were explored briefly in the pilot plant--soxhlet and steep-type hexane extractions. The results of these experiments are summarized in Table 2. The soxhlet apparatus functioned rather poorly with hexane, so both these runs were completed with several steep extractions to recover as much oil as possible. Cycle times were short, of the order of 7-15 min, resulting in little time for hexane to diffuse into and out of the flake mass. While the lower residual oil in the spent flakes of run 1 suggests higher overall extraction efficiency relative to run 2, the lower extraction yield (39.6% vs. 41.0%) and lower level of oil accounted for in run 1 (92.5% vs. 96.7%) both suggest that oil was lost in run 1. The loss possibly relates to the fact that extracted oil in run 1 was exposed to boiling hexane in the soxhlet pot for a much longer time. Resinous material found in the soxhlet apparatus after these two runs could account for oil loss by way of polymerization. Including the finishing steep segments, both soxhlet extractions were relatively effective because the spent flakes contained less than 1% residual oil.

The soxhlet thimble served as a reservoir for the two steep extractions. These cold extractions were less efficient than the overall soxhlet extractions as shown by the relatively high residual oil levels in the spent flakes, and by the lower extraction yields (89% of theory). However, note that all oil originally present in the flakes is accounted for in these runs, supporting the idea that resin formation leads to some loss of oil in the "hot" soxhlet extractions.

Some idea as to the relative extraction efficiency of these runs can be seen from Figure 6. Points on these curves represent extraction fractions from which oil was isolated and for which cumulative solvent/flake ratios and cumulative recovered oil were calculated. Since contact times for equivalent cumulative solvent/flake ratios were not necessarily the same, caution is necessary in interpreting these results. The initial eight cycles of soxhlet extraction 1 (Fig. 6, open circles) recovered 83% of the oil, with most of this recovery (80%) occurring in the first four cycles. The next 43 cycles (not shown) recovered only an additional 3% oil. Thus, the cycling portion of this run was inefficient for total oil recovery. The three finishing

TABLE 2

Pilot Plant Extractions of *Vernonia* Flakes

	Flakes			Oil			
Extraction method, run no.[a]	Kg extracted	Moisture, %	Oil,[b] %	Extraction yield,[b] %	% of theory	In spent flakes, %	Accounted for, %
Soxhlet, 1	5.0	7.32	43.2	39.6	91.5	0.43	92.5
Soxhlet, 2	3.5	7.32	43.2	41.0	94.9	0.80	96.7
Steep, 1	4.0	6.26	42.9	38.4	89.1	4.70	100
Steep, 2	4.0	6.26	42.9	38.5	89.5	6.67	(105)

[a] Soxhlet 1: 51 cycles and three steep extractions. Soxhlet 2: 22 cycles and six steep extractions. Steep 1: six 1-hr steeps. Steep 2: six 1/2-hr steeps.

[b] % of flake weight, dry weight basis.

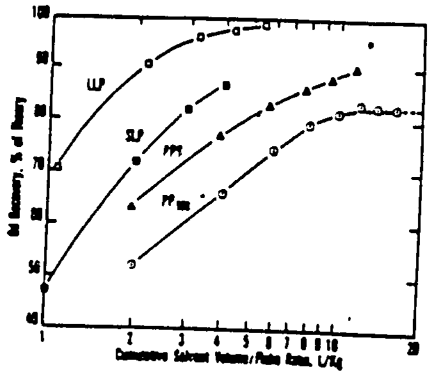

FIG. 6. Oil extraction efficiency as a function of total solvent volume used. PP$_{sox}$ = pilot plant soxhlet run 1; PPS = 60 min pilot plant steep; SLP = small laboratory percolation; LLP = large laboratory percolation; ● = mean of four preliminary laboratory runs (Table 1).

steeps account for the higher oil recovery shown for this run in Table II (91.5%).

Results of the two pilot plant steep extractions were the same; i.e., oil recoveries fall on the same curve (Fig. 6, open triangles) whether the steep durations were 30 or 60 min. Only points for the run with 30 min steeps are shown. The greater extraction efficiency of the steep extractions, relative to the cycling portion of the soxhlet run, is apparently due to the longer contact time between hexane and the flake mass within the cheesecloth bag.

The most efficient extraction was the large laboratory steep/percolation experiment (open squares) where contact time averaged *ca.* 1 1/2 hr at room temperature (see also Fig. 5). Diffusion into and out of the loose flake mass in the extraction cylinder was probably easier than in the tightly bound flake mass in the pilot plant runs. This percolation process more nearly reflects commercial extractor conditions insofar as the flake bed is concerned. Even the short contact time of 15 min for the small laboratory percolation experiment, also with a loose flake mass (solid squares), recovered oil more efficiently than the longer pilot plant steeps (open triangles). The single solid circle (●) in Figure 6 represents the average oil recovered in the four initial laboratory experiments (Table 1), which focused on enzyme inactivation. These extractions also utilized a steep/percolation procedure similar to the large laboratory extraction (open squares), although contact times were generally shorter and total solvent used was slightly more than doubled.

EVALUATION OF OTHER PROCESSING STEPS

Seed and Fiber Separation

Figure 7 summarizes the various processing steps used

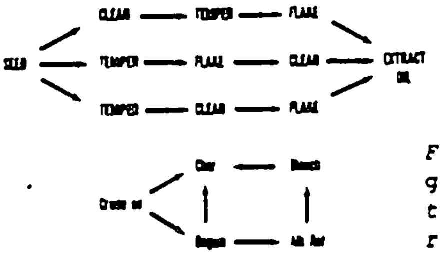

FIG. 7. Processing steps to V. galamensis oil. Char = charcoa treatment; Alk Ref = alkali refining.

in our studies. Concentrating on the upper portion of the figure first, the clean→temper→flake scheme is most logical in terms of standard processing procedures and would reduce bulk, saving energy and capacity in a processing plant. To be effective, however, cleaning equipment should mechanically manipulate the seed sufficiently so that the pappi and seed hairs are abraded from the seed. We had little success in straight screening or air aspiration, except to remove fine particles, dust, and some fiber (1-5%). Adequate precautions should also be taken to isolate this fibrous debris from work areas because of possible allergenic factors.

During tempering, the seed loses its pappus and most of the body hairs due to the tumbling, abrasive interactions in the moist environment of the tempering unit. This fibrous debris (Fig. 1C) agglomerates around shafts and stirring devices and 1-2% can be separated manually from the seed mass at this point. If tempered seed is flaked (middle scheme, Fig. 7) then *ca.* 18% fibrous material can be aspirated away from the flakes by repeated passes, but this process is inefficient; not only is flake loss a possibility, but such manipulations will lead to increased fines going into the extractor.

All our pilot plant experiments used the temper→clean→flake scheme (Fig. 7) where tempered seed was passed through a Bates Laboratory aspirator which removed 12-15% fibrous debris. Only the physical bulk of the uncleaned seed in the tempering unit is a drawback to this otherwise excellent process to separate seed and fiber. Fiber content of tempered, cleaned, and defatted flakes from this process was *ca.* 10-11% on a dry weight basis (Table 3).

Seed Flaking

A standard flaking mill with 12 in. smooth rolls set at 0.003 in. gave compact flakes of 0.002-0.003 in. thickness. The original seed length of 5-6 mm was generally retained while the width more than doubled to 3-3.5 mm. The snowy white interior of the seed glistens when viewed under a microscope due to the high oil content. Seed flaked at 5.3% moisture gave more fines than seed flaked at 7-10% moisture; the additional moisture and high oil content combined to give virtually intact flakes from each crushed seed (Fig. 1D). All our flakes were prepared at room temperature from seed that had been tempered and then air dried. Since we experienced no difficulty in preparing satisfactory flakes for our studies, we did not try to define an optimum seed moisture or to look at temperature as a factor in flaking the seed. The physical integrity of the flakes during mechanical handling may be dependent on seed moisture and temperature at the time of flaking. In our limited experience, the defatted flakes (Fig. 1E) retained their physical integrity rather well.

Oil Refining

The bottom portion of Figure 7 illustrates several oil refining steps investigated in our studies. Degumming with 2-4% water resulted in 2-3% oil loss as did bleaching with 2% of a neutral bleaching earth. However, rather stable emulsions were formed during alkali refining, resulting in losses of up to 17% oil, and more work needs to be done in this area if alkali refined oil is desired. FFA content of all our oils averaged 0.6%, and alkali refining reduced this to 0.1%. Charcoal was the only treatment that removed much color from the oil. Crude oil with color of Gardner 10 went to Gardner 6-8 upon 2% charcoal treatment, and to Gardner 2-3 with 5% charcoal treatment. With 2% charcoal oil loss was 5%, whereas with 8% charcoal the loss was unacceptably high at 22%. For current anticipated uses, the degree of refinement is probably not critical.

TLC Evaluation of the Oil

Figure 8 compares the TLC behavior of some *V. galamensis* oils prepared in our study (lanes 3-9) with several reference materials: *V. anthelmintica* (lane 1) and *Stokesia laevis* oils (lane 2); saponification products (FFA) of *V. galamensis* oil (lane 10); and methyl esters prepared by BF_3/MeOH treatment (lane 11) and by sodium methoxide/MeOH transesterification (lane 12). The major spots represented are (Rf; lane #): vernolic acid (0.2-0.3; 2,10); methyl 12(13)-hydroxy-13(12)-methoxy-octadec-9-enoates (0.25-0.30; 11); trivernolin (0.30-0.35; 1,3-9); normal fatty acids (0.35-0.40; 2,10); divernoyl triglycerides (0.40-0.45;

1-10); monovernoyl triglycerides (0.50-0.55; 2-9); methyl vernolate (0.55-0.60; 12); normal triglycerides (0.65-0.70; 1-9); and normal fatty acid methyl esters (0.75; 11-12). The *V. anthelmintica* oil consists largely of trivernolin, whereas the *Stokesia* oil normally has a more random distribution of the vernolic acid in the triglycerides (16). However, both oils had been prepared without adequate seed tempering and contained large amounts of FFA, 13% and 65%,

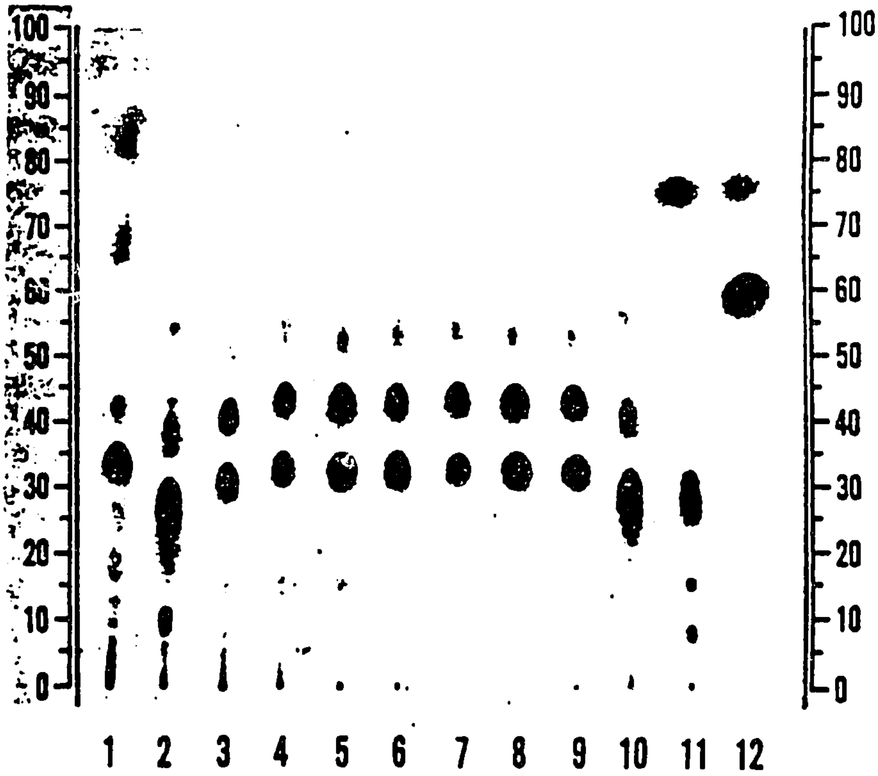

FIG. 8. TLC of epoxy oils, FFA, and methyl esters. (1) V. anthelmintica *oil (13% FFA); (2)* Stokesia laevis *oil (65% FFA). (3→9)* V. galamensis *oils: (3) and (4) laboratory extracted and 2% charcoal treated; (5) pilot plant soxhlet extracted and charcoal treated; (6) pilot plant steep extracted, crude; (7) degummed (6); (8) degummed and alkali refined (6); (9) degummed, alkali refined, and bleached (6); (10) FFA from saponification of* V. galamensis *oil; (11) methyl esters of* V. galamensis *oil by BF_3 method; and (12) methyl esters of* V. galamensis *oil by sodium methoxide in methanol.*

respectively. The major TLC spots from the *V. galamensis* oil are (by quantitative column chromatography): 45% trivernolin, 35% divernoyl triglycerides, 9% monovernoyl triglycerides, 5% normal triglycerides, and 6% other material. The trivernolin content is intermediate between that of *V. anthelmintica* and *E. lagascae* (7). The vernolic acid-containing triglycerides are in the ratio 51:37:12. The ratio of normal fatty acid methyl esters to methyl vernolate (lane 12) was found to be 22.5:77.5, while the same ratio (23:77) was found for the normal methyl esters to hydroxy-methoxy methyl esters from the BF_3 ester preparation (lane 11). Again, this same ratio (24:76) can be calculated for normal fatty acids vs. vernolic acid by using the triglyceride distribution given above for the *Vernonia* oil.

Analyses of Defatted Flakes and Oil

Table 3 lists analyses obtained on defatted flakes. The high crude protein level (42.5%) is accompanied by relatively high levels of crude fiber (10.9%) and ash (9.5%). Amino acid analyses of *V. anthelmintica* seed meal by VanEtten et al (31) indicated that methionine and lysine contents were limiting factors for its use as the only

TABLE 3

Analyses of *Vernonia galamensis* Defatted Flakes[a]

Analysis	%
Moisture	8.73
Oil	0.43
Protein (N x 6.25)	42.51
Fiber	10.85
Ash	9.52

Amino Acids:

Essential	g/16 g N	Other	g/16 g N
Arginine	7.21	Alanine	3.92
Histidine	2.27	Aspartic acid	8.40
Isoleucine	3.68	Cystine	1.18
Leucine	6.36	Glutamic acid	18.06
Lysine	4.82	Glycine	6.00
Methionine	1.88	Proline	3.66
Phenylalanine	4.33	Serine	4.79
Threonine	3.74	Tyrosine	2.99
Valine	4.46		

[a] Seed tempered, flaked, and defatted; dry weight basis; 43.2% oil in original seed.

source of protein for animal feeding. Normal growth rates have been reported (1) for rats fed autoclaved (but not raw) *V. anthelmintica* meal at a 20% dietary level for 90 days. While no feeding studies have yet been done with *V. galamensis* meal, its higher lysine, methionine, and phenylalanine levels relative to *V. anthelmintica* meal suggest an amino acid balance more nearly adequate for optimum rat and chick growth (31). The levels of essential amino acids (Table 3) may be compared with the following levels in defatted soy meal (32)--Arg 7.6, His 2.2, Ile 4.4, Leu 6.7, Lys 6.0, Met 1.4, Phe 4.5, Thr 3.7, and Val 4.5.

Oil analyses (Table 4) show that oxirane oxygen levels varied little, averaging 3.83%. Most of our film studies were done with oil having the lowest oxirane oxygen (3.58%) and highest FFA levels (1.35%). Oils which were chromatographically cleaner (less low Rf material by TLC) tended to require a catalyst for good film formation. Oil viscosity (112 cps) was not affected by refining procedures. The GLC analyses in Table 4 show the range of vernolic acid (72-78%) found in our crude or charcoal-treated oils. Some extraction fractions, e.g., as shown in Figure 5, had even higher vernolic acid levels (82-85%). The only acid present above 10%, besides vernolic, is linoleic (12-14%). Palmitic, stearic, and oleic acids each account for only 2% to 6% of the acids in the oil. The composition is quite similar to *V. anthelmintica* oil (1).

COATINGS FROM V. galamensis OIL

V. galamensis oil shows promise for use in the coatings industry, possibly as a coatings material in its own right. Films formed on steel Q-panels have exhibited outstanding adhesion and flexibility. Table 5 shows the metallic driers and baking conditions used in preparing the coatings and results of Sward hardness tests on the films. Drier concentrations ranged from 0 to 0.2% by weight, and baking times ranged from 30-60 min at 150 C, 30-120 min at 175 C, and 10-20 min at 200 C.

Coatings formed under these conditions were evaluated for their physical properties, e.g., hardness (Sward test), flexibility (direct and reverse impact and conical mandrel), and adhesion, and were evaluated also for their chemical resistance to alkali (pH 9.9), acid (5% HCl), and solvent (xylene).

With regard to hardness: (a) there was no increase with aging over 3 weeks; (b) there appeared to be an increase in hardness with added driers (vs. none), *cf.* A & B, D & F (Table 5), but note that at the highest tempera-

TABLE 4

Analyses of *Vernonia galamensis* Oil

Analysis	No. of samples	Value Range	 Average
Oxirane oxygen, wt %	13	3.58-3.92	3.83
Free fatty acids, wt %	11	0.39-1.35	0.58
Free fatty acids in alkali-refined oil, wt %	4	0.10-0.12	0.11
Gardner color in:			
Crude oil	--	10-11	
Degummed oil	--	10-11	
Char-treated (2%) oil	--	8-9	
DRBC oil[a]	--	6-7	
Char-treated (8%) oil	--	2-3	
Viscosity, centipoises	12	107-119	112
Fatty acid composition, %[b]:			
Vernolic		72.2-78.0	
14:0		Trace	
16:0		2.7-3.3	
16:1		Trace	
18:0		2.7-3.9	
18:1		3.6-5.6	
18:2		12.6-14.0	
18:3		Trace-0.3	
20:0		0.2-0.5	
20:1		0.2-0.4	

[a] Degummed, alkali-refined, bleached, and 2% charcoal-treated.
[b] As methyl esters by GLC.

TABLE 5

Coatings on Steel Panels from *V. galamensis* Oil

Run	Drier system % metal Co	 Mn	 Zr	Baking schedule Temperature, C	 Time, min	Sward hardness at days of aging 3	 21
A	---	---	---	150	60	4	6
B	0.01	0.01	0.10	150	60	12	10
C	0.01	0.01	0.20	150	30	4	4
D	---	---	---	175	30	2	2
F	0.02	0.02	0.20	175	30	8	4
G	0.01	0.01	0.10	175	60	16	15
H	0.01	0.01	0.10	175	120	25	24
I	---	---	---	200	20	10	12
J	0.01	0.01	0.10	200	10	6	4
K	0.01	0.01	0.20	200	20	12	12

ture, driers did not increase hardness, *cf.* I & K; and (c) there is increased hardness with baking time, *cf.* B & C and F, G, & H, and also an apparent increase with baking temperature.

Color of the coatings increased with the baking temperature, e.g., at 150 C the coatings were nearly colorless, while at 200 C they were golden yellow. Increased baking times also increase the color.

Chemical resistance to alkali was very good considering all the triglyceride ester groups in the film. Resistance to 1% Spic and Span solution exceeded 72 hr for panel K and 31 hr for panel I (Table V). Films baked at 200 C generally had improved properties, probably because they are more thoroughly cured and crosslinked. All films resisted 5% HCl for over 48 hr, although vapor penetrated some and rusting then eventually occurred. All films resisted xylene for over 8 hr. Some softened after 24 hr, but panels baked at 200 C, e.g., I and K, were unaffected.

The physical properties of these films are their outstanding features. All films withstood 160 in.-lb of direct and reverse impact, indicating extremely good flexibility and resistance to chipping. All films passed the conical mandrel test, also illustrating their flexibility, excellent adhesion to substrate, and cohesive film properties. Coatings readily withstood cutting, drilling, and trimming without loss of adhesion or chipping at the cut edge. A pigmented coating was prepared using TiO_2 (20%, 200 C, 20 min), which exhibited these same good properties.

CONCLUSIONS

Oil obtained from *V. galamensis* seed is suitable for preparing baked films or coatings. Preventing lipid hydrolysis during oil extraction is no problem if attention is given to moist tempering of the seed prior to flaking, crushing, or grinding. Since the oil level is high, a prepress solvent extraction process may be possible and would likely be most economical, in which case proper tempering prior to pressing would be necessary to give low FFA oil. Ways to remove the hairy fibers from the seed need to be further explored since the economics of handling, storage, and processing will be affected by this characteristic.

Since work reported here was completed, we have found that not all our oil samples were equally suited for *uncatalyzed* polymerization, possibly because natural promoters of film formation may be removed during oil extraction or refining steps. Additionally, experiments have shown that this type of polymerization to hard coatings is not limited to *V. galamensis* oil, and may be characteristic of most high-epoxy oils or materials. For example, both *V. anthelmintica* and *Stokesia laevis* oils formed films under similar conditions, though they contained high levels of FFA. And compatibility of *V. galamensis* oil with other coatings materials appears promising.

ACKNOWLEDGMENTS

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Conservation versus Development in East Africa's Drylands

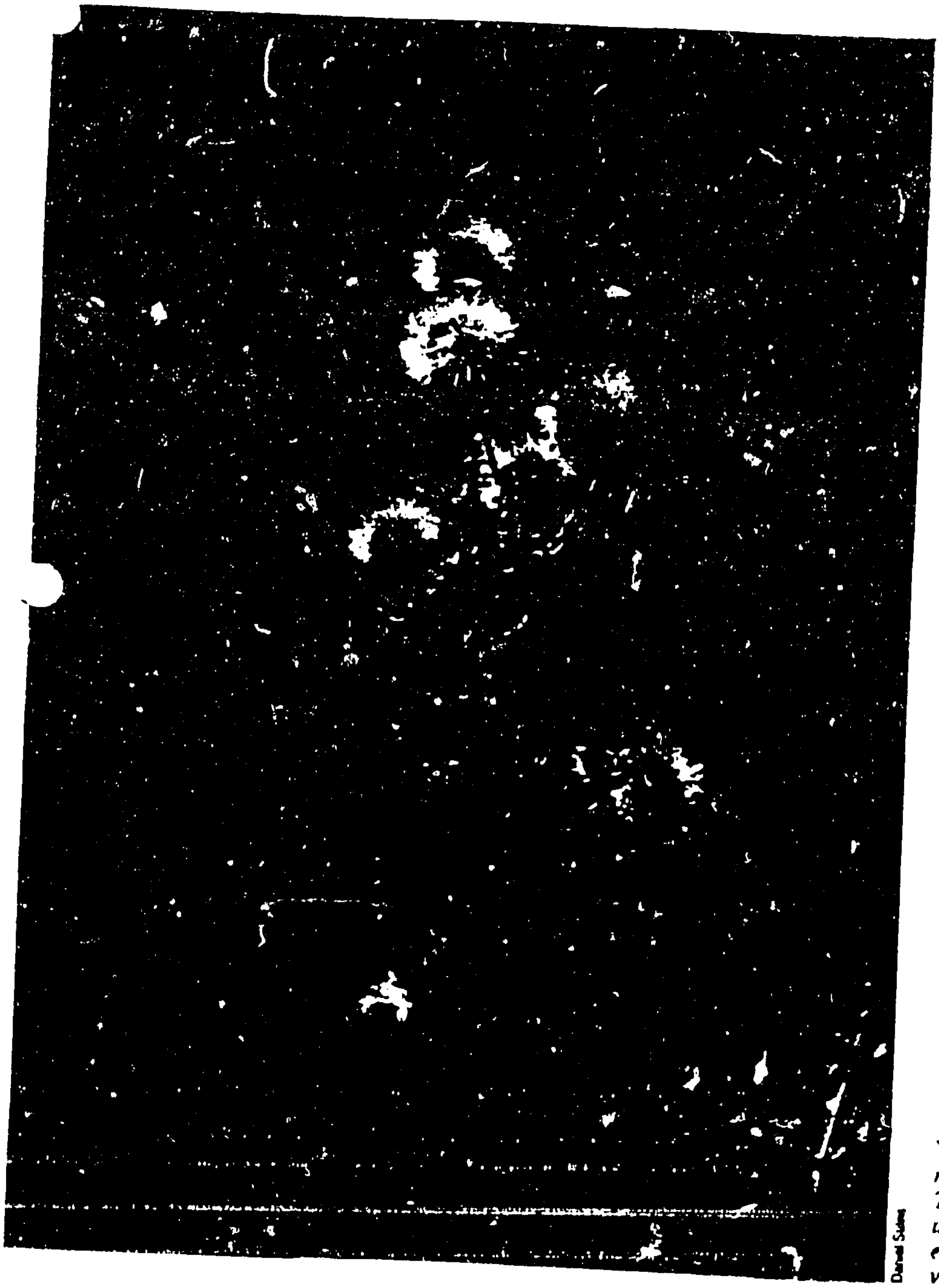
by Daniel Stiles

Does the economic potential of some indigenous plants offer a possible solution to the conflict between people and wildlife in East Africa's marginal lands?

Much of East Africa is made up of 'drylands', defined by the United Nations as the arid, semi-arid, sub-humid and productive parts of the hyper-arid climatic zones. Most of the larger game parks are found within these climatic zones as well. Today, it is largely within these dryland regions that the battle to conserve wildlife is taking place. The fight has largely already been lost in the high potential agricultural areas, except for a few pockets of protected forest or national parks, which find themselves under great pressure from the surrounding population.

More and more people every year, particularly in Kenya, are moving from the overcrowded high potential farmlands into the bush of the drylands. Slash and burn shifting cultivation and livestock grazing are the typical forms of subsistence of these poor segments of East African society. Without expensive inputs such as irrigation, fertilisers and pesticides, it is very difficult to practise sedentary agriculture and build up a highly productive farm. Shifting cultivation and overgrazing by livestock are leading to destruction of the natural vegetation – mainly various types of thorn bush and savannah, which also happen to be the habitat of the majority of East Africa's remaining wildlife.

There is still abundant land to support



Daniel Stiles

Vemonia galamensis *might well be the most important new plant for the 1990s. The seeds produce an oil and epoxy acid that have great potential as an environmentally sound replacement for volatile solvents*

... drylands

viable wildlife populations, but with an exponentially increasing human population it is clear that this situation will not last very far into the future – particularly with the destructive land use practices of today. Even the use of extensive crops such as cotton, wheat and rice, which are favoured by local governments and aid agencies for 'proper' agricultural development in the drylands, results in the destruction of the natural vegetation . It also leads to the long -term environmental problems of soil salinisation, a build up of toxic wastes and other soil, water and health hazards. They require high inputs.

It has become a cliché to talk about 'environmentally sustainable development', but nevertheless the concept is with us for the forseeable future. It is a concept that has many proponents but almost no practitioners. Kenya's President, Daniel arap Moi, has pointed out in many speeches recently that the future in Kenya lies in the drylands and he has implored people to find ways of making them productive. The same could be said for the rest of East Africa. If sustainable development is not carried out right from the beginning in the fragile drylands, the future will be short. Already, large parts of northern Kenya, central Tanzania, north-eastern Uganda and the dry Rift Valley have undergone desertification, but little land has been irreversibly affected and it is not too late to rehabilitate it.

One area that has, strangely, received little interest from local governments or aid agencies is the use of indigenous natural resources that need no or low inputs. The most obvious natural resource is the indigenous vegetation. Not very pleasant to look at in the dry season, this *Acacia-Commiphora* thorn bush bursts into flowers and greenery during and after the rains. Myriads of wild animals and birds make use of its abundance for food and shelter. Does it have anything to offer to humans, other than secondarily to our livestock?

From the times of antiquity and the first century A.D. *Peryplus of the Erythraean Sea*, and through the accounts of Persian, Arab and Indian traders from the 9th to 18th centuries, the aromatic resins of Zinj (East Africa) have been mentioned as valued items of commerce. The principle resins are frankincense and myrrh. Few people realise that the East African drylands are full of the trees which produce these resins, and many other resins, gums, oils and extracts of high economic potential. There are also shrubs with great potential, such as *Aloe, Vernonia, Lawsonia* and others.

The products from these trees and shrubs are a renewable resource, and commercial exploitation of them can be carried out in such a way that no environmental damage is done to the land. Since wildlife poses little or no threat to the products (except for baboons and ostriches which eat gum), the traditional conflict between farmer and wild animal is largely avoided. Although there are many trees and shrubs with potential, let's review a few of the better developed ones:

Acacia senegal: This well known 'wait-a-bit' thorn tree produces gum arabic, a natural substance sought after for use as an emulsifier or stabiliser in a wide variety of food and beverage products, printer's ink, paper, textiles, pharmaceuticals, etc. The Sudan currently provides 80-90 per cent of the world's supply, but there is great scope for increases in production to meet market demand. Over the last several years, due to falling production and rising prices, many users have switched to other gums or starch synthetics, but gum arabic is ideally the most desired because of its particular properties. This tree can grow in very dry areas (less than 300 mm average annual rainfall) in very poor soils. Gum collecting and marketing is being done on a small scale in parts of Kenya and Tanzania (and Somalia), but it is inefficient and quality control is poor.


Daniel Stiles

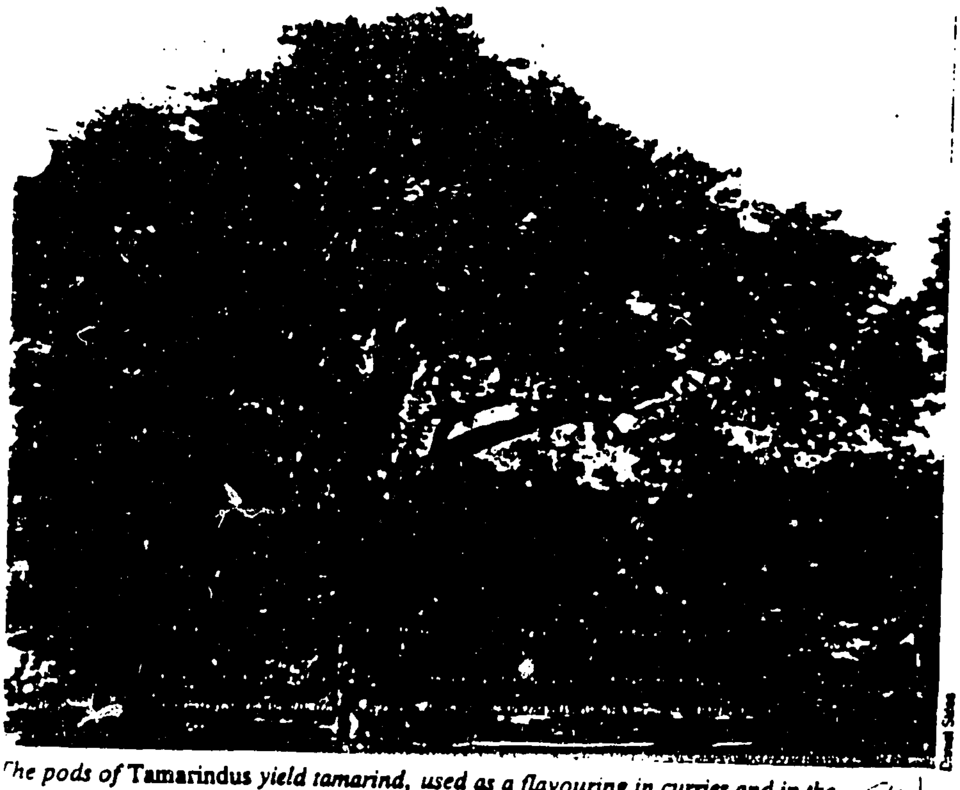
The aromatic resin of Commiphora *trees is used in perfumes, food flavourings and incense.*

Sterculia sp: In India one species of this tree produces a gum called *karaya*, which is of considerable commercial and industrial importance. It is used as a thickening agent for printing pastes in the textile industry and in pharmaceutical and medicinal products such as lozenges, emulsions, lotions, sprays and pastes. It is also used in laxatives, and one collector in Kenya is selling it to a French company for this purpose. Other important uses for the gum are in the paper and leather industries, and it is employed in the food, baking and dairy industries because of its binding and water-holding capacities. Many *Sterculia* species have edible seeds, rich in fatty oil. If one or more of the East African species yields gum similar to *karaya*, it would have good market potential.

Boswellia sp: This small, spindly tree produces frankincense, also known as olibarium. This resin is used in the production of incense, lotions, perfumes and food flavours. Top quality frankincense 'tears' command a very high price on the international market.

Commiphora myrrha: The taxonomic situation of the commiphoras is confused and other names have also been given to the myrrh tree. In fact, more than one species might produce the myrrh resin. Myrrh is used in incense, pharmacology, perfumes, in the formulation of bitters and flavoured wines, and in flavouring beverages, candy and soups. An unknown quantity of myrrh is collected and exported from Kenya's north-eastern region to China and Japan, some of it through Somalia.

Commiphora erythraea/holtziana: This tree produces the opopanax resin, which is similar to myrrh and used in perfumery and flavouring of alcoholic beverages. Another


Daniel Stiles

The pods of Tamarindus *yield tamarind, used as a flavouring in curries and in the making of juice and other food products.*

similar in use to opopanax. These are also exported from north-eastern Kenya to the Far East.

All of the *Boswellia* and *Commiphora* resins are often processed into resinoids and essential oils prior to their use, thus offering a secondary agro-industry in East Africa if they were to be developed. Studies are currently underway in the U.K. on the medicinal properties of the resins, which so far look very promising.

Tamarindus indica: This attractive tree, which grows wild but can also be used as an ornamental plant in gardens, produces a large seed-pod and seeds which are edible. The fruit pulp can be used in curries or made into a drink or sherbet, and the seeds are eaten roasted, boiled or as flour. They are also used in the sizing of cloth, paper and jute products and as a vegetable gum in food processing.

Lawsonia inermis: The leaves and young branches of this shrub, which grows along river and stream courses, produces a reddish-orange dye called henna used in the Muslim world for decorating women's hands and feet and dying men's beards. In the West it has become very popular for use in hair shampoos, conditioners and rinses. Extracts are used as wood stain and fabric dye and the essential oil of the flower is used in perfumes.

Aloe sp: Aloes from Barbados and South Africa produce juices from the succulent leaves which go into skin creams, ointments and cosmetics. The latex is used in laxatives and veterinary medicines. East African aloes have potential in these areas, but past experience has been unfortunate. Large numbers of aloes were destroyed in northern Kenya in the early 1980s when word went around that the leaves and juice were worth money. This prompted President Moi to ban their destruction. Since aloe juice quickly loses its potency, due to oxidation, unless protected with additives, the several tons collected and dehydrated never found a market. Following testing, aloe species with economic properties ould be grown and the juice properly treated for export sale.

Vernonia galamensis: This annual shrub, which has several subspecies, is widespread in East Africa throughout many climatic zones. The tiny seeds produce an oil and an epoxy acid that have tremendous potential in the manufacture of plastics, nylons, industrial coatings, adhesives, varnishes and paints. It can act in the place of volatile solvents, which are being banned by environmental protection legislation as the gases they give off contribute to destruction of the ozone layer and to the greenhouse effect. The oil is biodegradable, which introduces the possibility of the biodegradable plastic bag. The plant likes to grow in shade, so it would be a good candidate for cultivation in an agro-forestry configuration, perhaps in plantations of some of the trees mentioned above.

Daniel Stiles

The author in front of a Commiphora, *producer of myrrh, opoponax and other valuable resins.*

Of course, the potential market for these products is a crucial factor. Markets are strange things, and they interact strongly with the quality, quantity, reliability of supply and price of any given product, which determine ultimate demand. Today's demand for a product is not necessarily an indication of tomorrow's, if the supply factors named above change. The supply of most gums and resins today is haphazard and relatively expensive, which limits demand. A well organised and managed supply, howe could dramatically change the situat People – and industry – prefer h quality natural products to chemical a artificial substitutes if all else is equal.

All of the plants named above indigenous to East Africa and are a larg unexploited natural resource. There others not mentioned here. In some are the trees are numerous enough to all commercially viable tapping and collecti of the resins and gums in natural w stands. In other areas, particularly degraded land, it would be more practic to establish nurseries and plantations rehabilitate the land. With proper plannir and management, conservation of wildli could be integrated into the development these plants and their products. Who sa money doesn't grow on trees?

Daniel Stiles received his PhD in anthropology from the University of California, Berkeley. He first came to Kenya in 1971 to dig for early man at Koobi Fora and settled in Nairobi to teach at the university in 1977. From 1983 to 1988 he worked for UNEP and now he is an independent consultant and writer.

Vernonia, New Industrial Oil Crop

Does the pine tar smell of wet paint make you ill? It doesn't have to...smell, that is.

The characteristic odor of fresh paint is caused by the volatiles in it—molecules that readily evaporate into the air in large amounts, which makes them easy to smell.

These smelly organic solvents have become increasingly recognized as a factor in air pollution. New restrictions on their use have been passed in California, New York, and New Jersey, and other states are likely to follow.

But a new potential industrial oilseed crop *Vernonia galamensis* is the source of a diluent that could substantially reduce such air pollution, at least in oil-based paints, according to Agricultural Research Service botanist Robert E. Perdue, Jr. He has been actively researching the crop since 1984, although his interest in it dates back to the early 1960's, when he first collected some vernonia seed in Ethiopia.

Perdue works in ARS' Systematic Botany, Mycology, and Nematology Laboratory at the Beltsville Agricultural Research Center in Beltsville, Maryland.

The low viscosity of vernonia seed oil will permit it to be used as a solvent in paint, one which because of its unique chemistry will become part of the dry paint rather than evaporate into the air.

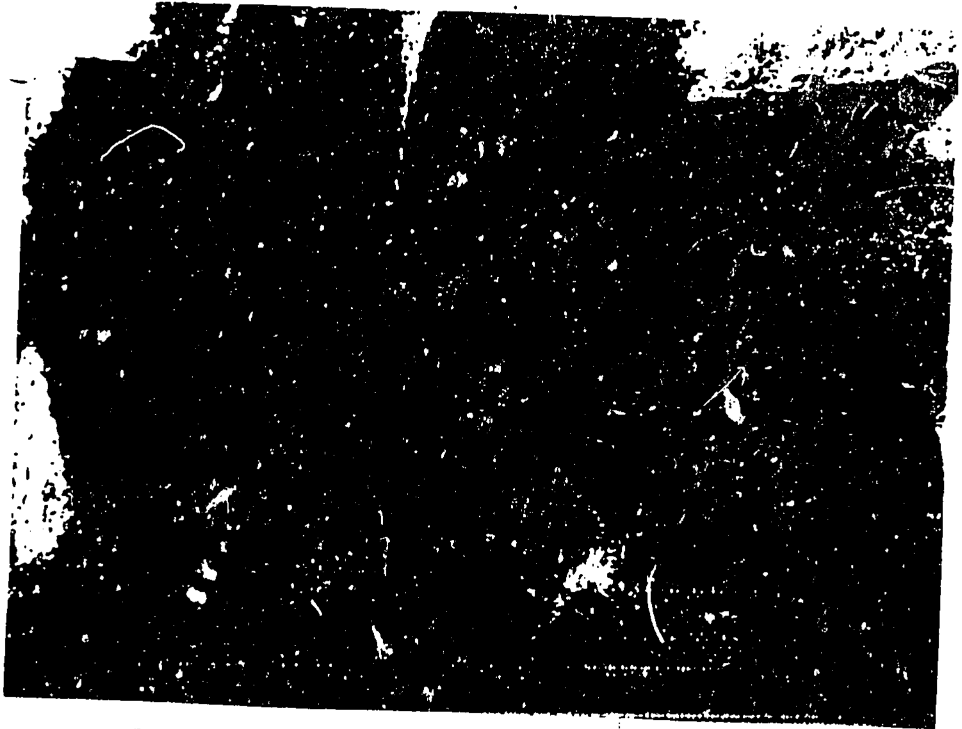
"Besides its potential for use in paint, vernonia oil has a lot of other industrial possibilities," Perdue says. "It could eventually be a replacement for petroleum as a source of the raw materials for components in the manufacture of plastics.

The plant, a native of Eastern and Central Africa, is a relative of the thistle. It is thornless, with lavender flowers that set 1-inch clumps of brown seeds.

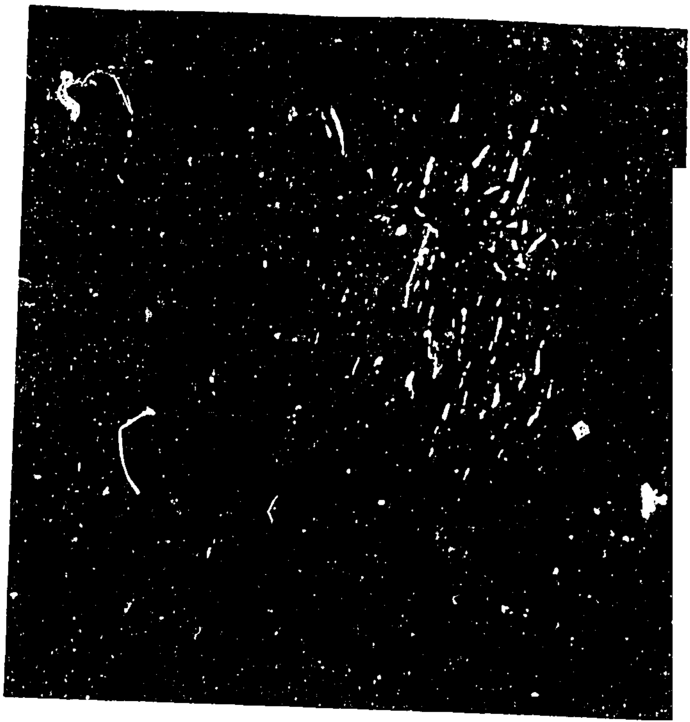
Commercial probability for raising vernonia rests in these seeds. "They are an incredible source of a naturally epoxidized oil," Perdue says.

Because the crop grows well in tropical and subtropical semi-arid environments with as little as 8 inches of rainfall, vernonia may be a welcome new crop in African countries such as Zimbabwe and Kenya. Agronomists in both nations are cooperating with Perdue in projects to discover the best ways to grow a crop that has never been cultivated before.

Agronomists in Zimbabwe doubled the yield from 1.2 metric tons per hectare in 1986 to about 2.5 in 1987 through improved management. (The 1987 yield is equivalent to 2,230 pounds



At the Chiredzi Research Station in Zimbabwe, Africa, ARS botanist Robert Perdue (left) and agronomist C.T. Nyati of the Ministry of Lands, Agriculture, and Rural Resettlement, inspect a field of *Vernonia galemensis* Its seeds (left) are a source of naturally epoxidized oil, which coating experts believe can be used as a non-air-polluting solvent in the manufacture of oil-based paints. (seeds K-3137-1, flower K-3137-2)



acre.) They expect they can increase that by breeding better varieties, Perdue says.

"This seems reasonable, considering that when soybeans were first grown in the United States in the 1920's, the yield was 660 pounds per acre and now the average yield is 2,040 pounds per acre and increasing," he says.

Researchers there have already discovered that the plants benefit from being topped—cut off at about 6 inches above the ground—to produce many branches that tend to flower and set seed at the same time, which enhances more even ripening. If they are planted too early, the plants can get as tall as 9 feet before flowering.

"One great thing about the crop is the staying power of the seeds," Perdue says. "They'll stay on the plants for 30 days or more after ripening, so a grower can wait until most of the seeds are ripe before harvesting, even if the flowers bloom at intervals.

At the moment, vernonia has limited possibilities as a crop for the continental United States. The plant doesn't flower until the days are shorter—a trait typical of most tropical plants. And when days are short enough to cause vernonia to flower, they are followed by frosts too soon to allow seeds to form.

"But recently, a variety that flowers 6 weeks earlier than any previously found has been collected in Nigeria, about 11 degrees north of the equator," Perdue says.

"What we need to do now is search the limits of vernonia's range, about 20 degrees north and south of the equator. I'll bet we find one that flowers early enough for it to set seed well in the United States," Perdue says. "Then it will make a great late summer/early fall crop for the Southwest."

Potential demand for vernonia oil as a diluent for alkyd-resin paints, th kind of oil-based paint used on build ings, has been estimated at 40 millio gallons, based on the use of 1 pint of vernonia oil per gallon of paint, acco ing to John C. Graham, director of th Coatings Research Institute at Easter Michigan University.

"Formulating alkyd-resin paint w vernonia oil could reduce emissions involved in photochemical pollution i as much as 160 million pounds per year," Graham says.

At 891 pounds per acre—the oil yie in the 1987 Zimbabwe tests—about 365,000 acres of vernonia would be required just to meet U.S. needs in th manufacture of alkyd-resin paint. "T figure doesn't include paint productio in other industrial countries nor the p tential demand from other uses of vernonia oil," he says.—By Kim Kaplan, ARS.

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87

Since starch makes up nearly three-fourths of the corn grain's composition, this component is receiving considerable attention as a raw material from which a variety of low-molecular weight chemicals can be produced that are now obtained from petroleum. Improved chemical and bioconversion technologies for starch and glucose have increased opportunities for starch-derived alcohols, polyols, and acids for markets now served mostly by petrochemicals. Starch and starch-derived polymers are entering new markets traditionally dominated by synthetic polymers. Synthetic polymer films and bottles are being produced that contain starch as a biodegradable component. Starch-synthetic polymer compositions are used as highly efficient aqueous fluid-absorbing agents in numerous applications. Other opportunities are emerging for such compositions as matrix-forming polymers for encapsulating chemicals and for a variety of other uses.

6

SPECIALTY CROP DEVELOPMENT AND GENETIC RESOURCES CONSERVATION IN A CHANGING WORLD

Henry L. Shands

U.S. Department of Agriculture

Demands of society for good stewardship of natural resources, cleanup of the environment, and subsequent biomass substitutes for fossil fuel resources will ultimately bring about greater use of nature's living plants for their chemical products. Products and by-products of agriculture's plants will increasingly be used for higher priority needs in support of human life. Medicinal plants, often little understood chemically but long used in tribal medicine, will continue to be sought and studied for their curative chemicals for human illnesses as molecular biology unravels the complex chemistries of their powers. Genebanks of plant genetic resources, offering a diversity of chemical products, enable breeders and molecular biologists to create and tailor new cultivars to produce useful products for human health and industrial needs. The world's genetic reservoirs, threatened by systematic destruction of habitat, need diligent efforts to survive and serve future generations. International treaties to effect a commitment by all nations will have a synergistic effect on conservation and development. Developing countries holding many of these resources lack infrastructure and capital to effectively protect and develop these resources. Government and industry together must combine in a concerted effort to alleviate the developing crisis. Investments in research and development now will have beneficial payoffs to society in the future.

7

VERNONIA GALAMENSIS: BOTANY AND AGRONOMY

Robert E. Perdue, Jr.

Agricultural Research Service, USDA, Beltsville, MD 20705

During the 1950's, an Agricultural Research Service screening program identified seed of *Vernonia anthelmintica* (native to India) as good source of vernolic, a naturally epoxidized fatty acid. The seed contain 23-31% oil of which 68-75% is vernolic acid. Since substantial quantities of epoxy oils are used to manufacture plastic formulations, protective coatings, and other products, an effort was made to develop this plant as a new crop for American agriculture. This was unsuccessful; yield was limited by poor seed retention. The seed fall off the plant as soon as they matured.

Later, Vernonia galamensis [illegible] seed retention and to be a superior [illegible] seeds contain about 40% oil of which about 80% [illegible] acid.

Vernonia galamensis, an annual that requires a well-drained soil, has been under development as a new crop in Zimbabwe since 1983. So far, there have been no problems with insects or disease. All agronomic research to date has been with crude unimproved germplasm collected in a dry area of Ethiopia in 1964, an accession almost tailor-made as a new crop. This germplasm is very uniform; there has been no selection of improved varieties.

"Topping" (removal of terminal buds when plants are about 15 cm tall) is a useful management technique: there are many branches from the base of the plant; height of plants at maturity is greatly reduced; and uniformity of seed maturity is enhanced. Seed yields in [illegible] were up to 2500 kg/ha and in 1988 up to 1800 kg/ha.

Vernonia galamensis is widely distributed in Africa from Senegal and Sierra Leone, east to Sudan and Ethiopia, and then south through Kenya and Tanzania to Zimbabwe and Mozambique. There are six subspecies, one with four taxonomic varieties. The center of diversity is in East Africa. Some of the taxa grow in areas with as little as 200 mm rainfall and have excellent drought resistance.

Two problems have been encountered in Zimbabwe. The original germplasm from Ethiopia is photosensitive; it flowers in response to daylength of about 11.5 hours. It is not synchronized with the rainy season and must be irrigated. This can be overcome with germplasm from an arid area of Sudan that flowers in response to daylength of about [illegible].5 hours. The poor seedling vigor of the Ethiopian germplasm can probably be improved with germplasm from West Africa.

RESPONSE OF VERNONIA GALAMENSIS TO PHOTOPERIOD

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A herbaceous annual, *Vernonia galamensis* is currently studied as a potential crop as a source for epoxytriglycerides and expoxy acids. When grown at Tifton (31°28'N) *V. galamensis* collections from Ethiopia (V-001) and Nigeria (V-004) failed to flower until October-November. Thus, research was initiated to study the effect of number of short days (SD, 8 hr light - 16 hr dark) on flowering. Plants were exposed to 0, 5, 10, 15, and 20 SD treatments starting on August 21, 1988 and planted in the field. Flowers were counted in October and November. Effect of topping to eliminate apical dominance on flowering was also studied. Results indicate that *V. galamensis* collections from Ethiopia and Nigeria are SD plants. These collections will not flower until October-November, and thus, will not produce seed before fall freeze at Tifton. The Ethiopian collection requires 10 or more SD for flower induction, while flower induction was observed in the Nigerian collection after 5 SD treatment. In natural day-length at Tifton, *V. galamensis* from Nigeria flowered 4-6 weeks earlier than the entry from Ethiopia. Topping increased the number of flowers.

V. galamensis accessions were evaluated for photoperiodic response under natural day length at Tifton, Phoenix (33°26'N), and Yuma (32°40'N), Arizona. Accessions in these studies included subspecies *afrosomtana* (V-020, [illegible]), *[illegible]* (V-016, V-017, [illegible]), *nairobensis* (V-011, V-012, [illegible], V-018, V-019, V-025), *galamensis* (V-013)]; [var. *australis* (V-008, V-009, V-010), *ethiopica* (V-001) *galamensis* (V-003, V-004) and *petitiana* (V-014, V-015, V-027, V-029, V-032)]. Plants at Tifton were also evaluated at 16 hour long day (LD) light by supplementing natural light with low light fluorescence lighting.

All accessions flowered when grown in SD with less than 12 hours of light. There was a difference in earliness with a few entries flowering in less than one month from planting while others took almost three months to flower. The number of SD required for flower induction also varies. V-004 requires 5 SD for flower induction while V-001 need 10 SD or more. Earliness appears to be related to the number of SD required for flower induction. The earliest *Vernonia* accessions needs the least number of SD. Eleven out of 24 accessions flowered when maintained at LD. However, it took longer for these entries to flower in LD than in SD. This indicates that accessions V-008, V-009, V-011, V-012, V-019, V-020, V-022, V-025, V-026, V-028, and V-029 are quantitative SD plants in which SD promotes earliness. Four of the entries: V-020, V-022, V-026, and V-029 took 6-9 weeks from seed germination to flowering in LD. The same accessions flowered in 4-6 weeks in SD. Accession V-032 also flowers early in SD.

9

IN VITRO CULTURE OF *VERNONIA GALAMENSIS* AND ITS POTENTIAL FOR OIL IMPROVEMENT

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Callus induction and regeneration of whole plants of *Vernonia galamensis* were achieved in tissue culture. Some of the calli thus formed were analyzed for free fatty acids using Finnigan 4500 computerized gas chromatograph-mass spectrometer.

Callus was initiated from immature seeds as well as from leaf segments of *Vernonia galamensis* on semi-solid medium supplemented with .05 mg/l 2,4-D, 2 mg/l IAA respectively. The calli were subcultured every four weeks on a maintenance medium. In the absence of growth regulators or in the presence of kinetin alone, some of the somatic cells in culture undergo organogenesis producing shoots only or both roots and shoots. Somatic embryogenesis was also observed at high frequency. In most of these cases several embryos were produced in each culture.

Callus tissues from the fourth subculture on the initiation medium were selected for oil extraction and subsequent chemical analysis. Gas chromatographic analysis of methylated pentane extract indicated the presence of stearic and palmitic acids.

Further work is in progress to determine the possibility of producing large numbers of plants of a superior single genotype that could provide a high percentage of oil. Additional work is also under consideration to screen calli from different varieties of *Vernonia galamensis* for oil at various stages of tissue development on a variety of growth media.

The present data suggest that there is a great potential for the improvement of *Vernonia galamensis* through tissue culture techniques.

PILOT PLANT EXTRACTION OF OIL FROM *Vernonia galamensis* SEED

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With 40-42% oil of which 75-80% is vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic), *Vernonia galamensis* seed is one of the best sources of natural epoxy acid. Even in its genetically unimproved state, this African species is a promising new crop for semiarid tropical areas. Research has shown that there is industrial potential for vernonia oil in PVC plastics, other polymer blends, baked coatings, and reactive diluents for paints and coatings systems. Processing the seed to oil and meal has been investigated on a small scale.

In this study we conducted seed conditioning, pressing and solvent extraction research in pilot facilities. To inactivate a robust lipase system, 200 lb batches of *V. galamensis* seed were conditioned at 195-200 F and >10% moisture in a French^{TM} 1-deck, 40-in D X 30-in H cooker/conditioner with sweep agitation. Conditioned seed (<3% moisture) was mechanically pressed in a French^{TM} 3 1/2-in mechanical press with variable speed drive and equipped with a 4-section cage with cored sleeves for steam heating or water cooling. The discharge cone was varied from 1/4-in to 1/32-in during operation to demonstrate feasibility of both full pressing and prepressing.

Press cake was extracted with hexane in a 1 1/2 ft^3 batch type, 4-stage percolation unit equipped with desolventizer/toaster and solvent stripping/distillation systems. The extraction column holds a 6-in square by up to 6-ft high mass of press cake. The 3-stage DT unit desolventized in stages 1 and 2 and toasted the defatted meal in stage 3. The oil stripper is capable of accepting a full miscella (25% oil) and producing a finished crude oil free of solvent. Excessive foaming of the Vernonia oil extract prevented complete stripping in this unit.

We will report results of this pilot-scale prepress/solvent extraction of Vernonia seed that show that lipase inactivation in the seed conditioner was successful, that prepressing successfully reduced oil level in the press cake to ca. 20%, and that solvent extraction reduced oil level in the defatted meal to 1-2%.

11

VERNONIA OIL BASED INTERPENETRATING POLYMER NETWORKS

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Vernonia oil can be polymerized through its epoxy groups to form a soft elastomeric material. Since there are more than two epoxy groups per oil molecule, the resultant product is crosslinked. When polymerized either simultaneously or sequentially, with a plastic-forming monomers such as styrene and divinyl benzene, impact resistant plastics or toughened elastomers result, depending on the overall composition. With both components crosslinked, these materials are known as interpenetrating polymer networks, IPN's. The morphology of these materials will be reviewed, with special reference to making still tougher products. The several compositions will be compared to their counterpart IPN's prepared from castor oil and lesquerella oil.

12

TRANSFERIPLION AND MAPPING OF *VERNONIA GALAMENSIS* GENES (CHLOROPLAST NUCLEUS)

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Not available.

13

Effect of hormone treatment on guayule seed germination and seedling growth

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Guayule (Parthenium Argentatum, Gray) seeds reqiure light and optimum temperature (17° ± 2°C) for germination. Seeds treated with 25% polyethylene glycol (PEG, MW 8000) germinate maximally (>90%) over a broad range of temperature (15° - 33°C) and accumulate more dry matter in the shoot tissue. Osmo-Conditioning with abscisic acid decreased the rate of dark germination and development of normal seedling. The inhibitory effects of abscisic on the rate of dark germination could be overcome with light or gibberellic acid without affecting the growth of the seedlings. The extent to which seed treatments with abscisic acid influence root and shoot growth will be discussed.

14

GENOTYPE-ENVIRONMENT INTERACTION IN GUAYULE

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It has been shown that guayule strains may respond differently to environmental conditions in their ability to accumulate rubber. In the cool Salinas Valley of California, McCallum's commercial strain 593 produced thick branches containing a high concentration of rubber. In the warmer valleys of California and in southwest Texas, 593 produced small plants with low rubber concentration. On the other hand, McCallum's strain 111 was the poorest rubber yielder in Salinas and the highest

36

APPLICATION OF VERNONIA OIL IN COATINGS INDUSTRY AND EPOXY RESINS

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Vernonia oil, a natural epoxidized vegetable oil, appears to be a very attractive raw material for large volume industrial applications in coatings and epoxy resins.

Vernonia oil is characterized by very low viscosity (in comparison to other vegetable oils) and has a potential for preparation of reactive diluents for high solid coatings by replacing conventional solvents. "Vernonia" reactive diluents will reduce air pollution (by reducing volatile organic compounds, and allow next-generation coatings formulations to meet the strict requirements of the EPA and California's South Coast Air Quality Management District.

Vernonia oil should also be able to simultaneously improve the two major disadvantages of epoxy resins: brittleness and high water absorption.

37

PROTEIN QUALITY EVALUATION OF *VERNONIA galamensis* DEFATTED FLAKES

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The nutritive value of *Vernonia galamensis* defatted flakes, prepared by the USDA, was determined using male weanling Charles River albino rats (A.O.A.C. Official Methods of Analysis). The rats (10 per group) were fed 10% protein diets containing Vernonia flakes for 28 days. Rats were then sacrificed and blood plasma samples prepared and organs examined and weighed. In a preliminary study, there was no mortality of rats fed Vernonia flakes and the hair coats and physical activity of the rats were comparable to that of controls fed casein. Plasma albumin, one of the more sensitive indicators of protein nutritional status, was comparable for the Vernonia flake-fed rats and the controls (1.92 ± 0.32 vs 2.09 ± 0.18 g/dl., respectively) ($P>0.05$). Kidney wts., as % of body wt., were significantly higher (1.32 ± 0.10 vs 1.07 ± 0.09, $P<0.05$) for the rats fed Vernonia flakes. Results of a bioassay of 5 other batches of Vernonia will be reported. Results to date of the feeding trial suggest that Vernonia defatted flakes have potential as a new protein source for animal feed.

CHEMICAL EVALUATION OF VERNONIA GALAMENSIS DEFATTED FLAKE

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Vernonia galamensis is an indigenous African plant with promising economic value both as a renewable raw material source for the chemical industry and potential component for the animal feed industry. Recent investigations have centered on the plant's seed oil (38-40%), with primary emphasis on the oil's rich vernolic (cis-12,13-epoxy-cis-9-octadecenoic) acid content (72-80%). On the other hand, little attention has been given to the defatted flakes which is considered in this study.

The flake is rich in protein (44%). Methionine was found to be the first limiting amino acid, with lysine the second when calculated based on the FAO Provisional Scoring Pattern. The carbohydrate fraction (6.57%) is rich in sucrose (35.81±0.06), fructose (28.76±0.11%) and glucose (11.64±0.18%). Levels of the minerals (mg/g)— calcium (11.08), potassium (14.18) and magnesium (6.90)— not only meet nutritional requirements, but are also higher than those of contemporary oil seeds. The phosphorus is high (644 mg/g), probably accounting for the fairly high phytate (25.42±0.06 mg/g) content, although this level is slightly less than what is observed in the AACC wheat bran standard (31.42±0.03 mg/g).

Residual oil content of the defatted flake was found to be approximately 0.5%, but could be higher depending on the method of extraction. Lipid analysis shows non-nutritive vernolic acid as the major (76.06±1.80%) component of the saponifiables (97.74±0.20%). C18:2 (11.64±0.69%), C16:0 (2.22±0.12%) C18:0 (2:63±0.11%), C18:1 (6.58±0.19%), C20:0 (trace) were all identified.

Sterols constitute the major (94.65±0.08%) component of the unsaponifiables (2.06 ± 0.16%) with β-sitosterol (32%; and Δ^5-avenasterol (30%) being the major constituents. Cholesterol was low (4.6%). Phytochemical screening for other possible toxicants did not give significant levels of antinutritive components.

Although no digestibility studies have been carried out, these results nevertheless indicate potential nutritive qualities of the defatted flake. The presentation will describe these results.

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VERNONIA OIL ECONOMICS

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There is an urgent need for a new crop for semi-arid lands of Africa and other regions of the Third World to increase employment in rural areas, provide import-substitution products to save foreign exchange, and provide exportable products to earn foreign exchange.

Vernonia galamensis, a rich source of a unique seed oil, has been under development as a new crop in Zimbabwe since 1983 and there is increasing interest in other countries like Kenya and Brazil where efforts to develop vernonia are getting underway.

Vernonia oil is a versatile product with potential applications in the formulation of paints, plastics, lubricants, and other industrial products. Samples for market oriented evaluation have been requested by many industrial, government, and university research laboratories.

This paper will provide a preliminary farm-to-market economic analysis to estimate the cost of vernonia oil delivered to a U. S. industrial consumer.

40

LECTINS IN *VERNONIA GALAMENSIS*

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Not available.

41

ECONOMIC IMPLICATIONS OF GUAYULE CO-PRODUCTS FOR A COMMERCIAL INDUSTRY

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The profitability of a guayule industry is determined by the difference between the costs of production and processing and the revenue from guayule rubber and its co-products (resin, low-molecular-weight rubber [LMWR], and bagasse). The cost to produce guayule rubber in central Arizona in 1989 is approximately $1.30 per pound (at current yields of 400 pounds per acre per year). For guayule to show a profit based on rubber revenue alone, yields would need to be increased to over 1,200 pounds per acre per year at the current price for *Hevea* rubber of $0.50-$0.55 per pound F.O.B. New York.

Consequently, because the market price of guayule is essentially set by the world price of *Hevea* rubber, the greatest opportunity for increasing profitability is to find new and valuable uses for the co-products. The values of guayule co-products are currently estimated to be $.20 per pound for the resin/LMWR, and $0.02 per pound for the bagasse if it is used as fuel in the co-generation of electricity. If co-product values could be increased to $.50 per pound for resin/LMWR and $0.05 per pound for bagasse, along with a rubber yield increase to 800 pounds per acre per year, guayule could become an economically viable crop.

Preliminary research results have suggested that resin and LMWR also show good potential to increase profitability as value-added products.