SEED PRODUCTION TECHNOLOGY

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(editors)

International Center for Agricultural
Research in the Dry Areas (ICARDA)

The overall objective of the International Center for Agricultural Research in the Dry Areas (ICARDA) is to increase agricultural productivity and food availability in both rural and urban areas, thus improving the economic and social well-being of people in developing countries, particularly in North Africa and West Asia. The center focuses mainly on winter rainfall areas with 200-600 mm annual precipitation. When appropriate, research also covers environments with monsoon rainfall or irrigation.

ICARDA is a world center for the improvement of barley, lentil, and faba bean, and a regional center for improving wheat, chickpea, farming systems, livestock, and pasture and forage crops. The training of agricultural researchers from developing countries and the communication of research results are an important part of ICARDA's activities.

ICARDA is a non-profit research center established in 1977 by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR, an informal association of donors including governments, organizations, and private foundations, supports agricultural research worldwide to improve food production in developing countries, through a network of 13 international research institutions, including ICARDA. The network covers crop and livestock systems that supply three-fourths of the food supply of the developing world.

Seed Production Technology

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FOREWORD

Better seed production technology is vital to furnish quality seed of improved varieties. For ICARDA's agricultural research to produce practical results, this seed must reach the farmer, who should also be convinced of the benefits of using it. The ultimate payoff is more and better food for the developing countries of the Middle East and North Africa--the basic aim of ICARDA.

The countries of the region are extremely diverse both in the type of agricultural systems evolved and in the climatic conditions confronted by farmers. Many new crop varieties are already available, but the region's seed production infrastructure--at different levels of development in various countries--needs further strengthening. This book therefore lays out the "ground rules" for seed production--a plethora of options from which each country must select the most suitable. The authors have aimed to produce a practical handbook for seed producers and technicians to keep them abreast of the latest technologies available.

The genesis of this book was a symposium held in March 1981, which was attended by 33 seed specialists from 16 developing countries and sponsored by ICARDA and the Seed Testing Station of the Royal Netherlands Government (RPvZ). As a result, the same sponsors held a seed production course at ICARDA in April and May 1981, attended by seed technologists from 10 Middle Eastern and North African countries. The course lectures were published as Seed Production Technology in 1983.

On behalf of ICARDA, I would like to express deep appreciation for extensive assistance from the governments of The Netherlands and the Federal Republic of Germany, which jointly sponsored the third seed production training course in 1984.

I hope that this revised version of Seed Production Technology -- substantially expanded to cover a more comprehensive range of topics -- will prove a valuable tool for seed growers both within and outside the region.

Mohamed A. Nour
Director General
ICARDA

INTRODUCTION

The information in this practical guide for seed producers and technologists has been distilled from two sources: the experience of the national research programs of the Middle East and North Africa, and the expertise of those who have conducted seed technology training courses in the region. The book is intended as a reference for all concerned with seed production, processing, marketing, and distribution, as well as for agricultural policy makers.

The first section of the book gives an overview of the seed production situation in the region, and outlines the components of a seed production industry. The case studies that follow illustrate how seed industries have developed in different countries. The bulk of the book is devoted to techniques and methods for seed production, including the certification, testing, processing, storage, and marketing of seed. Producing seed of the crops on which ICARDA concentrates has special problems, which are addressed in the final section.

The editors and ICARDA would like to express particular appreciation for the generous support of the Government Seed Testing Station (RPvZ) of the Royal Netherlands Government, and for the additional assistance of the German Agency of Technical Cooperation (GTZ).

The efforts of Mr W.J. van der Burg, RPvZ, and Dr P.K. Agrawal, Indian Council of Agricultural Research, (ICAR), are most gratefully acknowledged; without their review of selected chapters, and valuable suggestions, the book could not have been produced in this form.

We also extend deep gratitude to Mr Alexander Heydendale, Agricultural Attache of the Netherlands, for his keen interest in ICARDA's seed production work; as well as to Dr Ekkehard Clemens (GTZ) and Dr G.J. Koopman (now Deputy Director General-International Cooperation, ICARDA) for arranging financial support from the Netherlands and German governments. We thank, as well, ICARDA's Director General Dr Mohamed A. Nour, for his staunch support of the center's seed production efforts, including this book. We are also grateful to the national research programs of the region for providing essential information.

Thanks are also due to the staff of ICARDA's Scientific and Technical Information Program (STIP): Ms Fiona Thomson for editorial assistance, Ms Sylva Cholakian for typesetting, Mr Abdul Rahman Hawa and Mr Hassan Khairallah for artwork, and Mr Fouad Wehbe for printing. Ms Samira Maksoud of the Cereals Program typed the manuscript.

Editors

CONTENTS

Status of Seed Production in the ICARDA Region

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Quality seeds of improved varieties are the key to agricultural progress. The production potential and other desirable characteristics of seeds set the limits on production. Other inputs such as fertilizers, pesticides, herbicides, and overall crop management help to realize the production potential of seeds.

Seed has been an important agricultural commodity since crops were first domesticated. Part of the success of a farmer's crop depends on the quality of seed he plants. Even good management cannot produce good yields from a low-yielding, unadapted variety. If the farmer plants a mixture of disease-susceptible varieties with different crop durations and plant heights, his yields will be low and the diseased plants may contaminate his entire harvest. If his seed has low viability, the plant stand will be poor. Similarly, if his seeds are mixed with inert matter or weed seeds, his crop will be infested with weeds and yields will go down.

Farmers are gradually becoming seed-conscious and are willing to pay higher prices for quality seeds of improved varieties. The seed industry covers a broad range of activities such as crop improvement, production, and certification. Seed quality control, processing, and marketing also form integral parts of the seed production infrastructure.

The ICARDA region covers the countries of West Asia and North Africa (Fig. 1), stretching from Morocco in the west to Pakistan in the east, and from Turkey in the north to Sudan in the south. Seed production and related activities are not well developed in the region and vary from one country to another. The lack of seeds of improved varieties for farmers is one of the most important constraints to

increased productivity, making most countries in the region unable to utilize the fruits of crop improvement work being done at national and international centers. Several countries do have good crop improvement and testing programs but lack good facilities to multiply varieties identified as superior lines. In spite of considerable research effort, therefore, most of the area under commercial cultivation is still planted with old cultivars that do not respond to improved agricultural practices and are susceptible to diseases and pests. For crops with which ICARDA is concerned, seed production efforts in the region are better for wheat and poor for barley, food legumes, and forage crops.

It is imperative to develop a functional seed production program--the weak link at present--alongside crop improvement and varietal testing activities. Most of the countries in the region are interested in improving overall seed production, certification, quality control, processing, storage, and marketing facilities. A sound seed production program requires suitable legislation, aggressive crop improvement activities, proper certification and quality control agencies, and a thorough marketing and distribution network.

Different factors affect seed production in different countries, as shown in Table 1. In most of the countries, seed production is adversely affected by diseases, although the insect problem is not very severe. The lack of improved seed, trained manpower, and facilities are other constraints. Most of the countries still must develop effective seed legislation to regulate production and marketing of quality seed (Table 1), as well as adequate facilities for testing, processing, storage, transporting, marketing, field inspection, and credit (Table 2).

In most of the countries, however, facilities for varietal improvement and testing do exist (Table 3). Most countries have regulations for varietal release, and the nucleus (breeder) seed of released varieties is being produced by research stations. In some countries, however, the link between breeder seed, nucleus seed, foundation seed, and certified seed is poor, apparently because of the lack of a strong seed production certification agency (Table 3). Also, some countries have inadequate facilities for quality control, seed processing, marketing, and distribution--essential components of the seed production infrastructure.

The present stage of development of seed production in the 20 countries is presented in Table 4 for wheat, barley, forages, and food legumes. Production systems are rated as developed, semi-developed, poorly developed, and non-existent. In wheat, only eight countries are fully-developed, and 11 are semi-developed, while in barley, only one is fully-developed. None are fully-developed in forages or food legumes.

The situation, however, is changing. National programs have strengthened seed production infrastructure and, in recent years, more

facilities and skilled personnel have been provided to this sector. ICARDA is actively engaged in assisting national programs in this area through training, provision of some breeder seed, and advice. In 1985, a seed scientist was appointed at the center whose principal responsibility is to assist national programs in improving their seed production industry so that good quality seeds of improved food crops become easily available to farmers.

Acknowledgement

The author is grateful to the many scientists from the national programs who provided valuable information to enable the presentation of the tables in this chapter; the tables are, however, indicative at best. In some cases, a country's facilities may have improved considerably since the data were gathered for the tables; the author would appreciate receiving information on such changes.

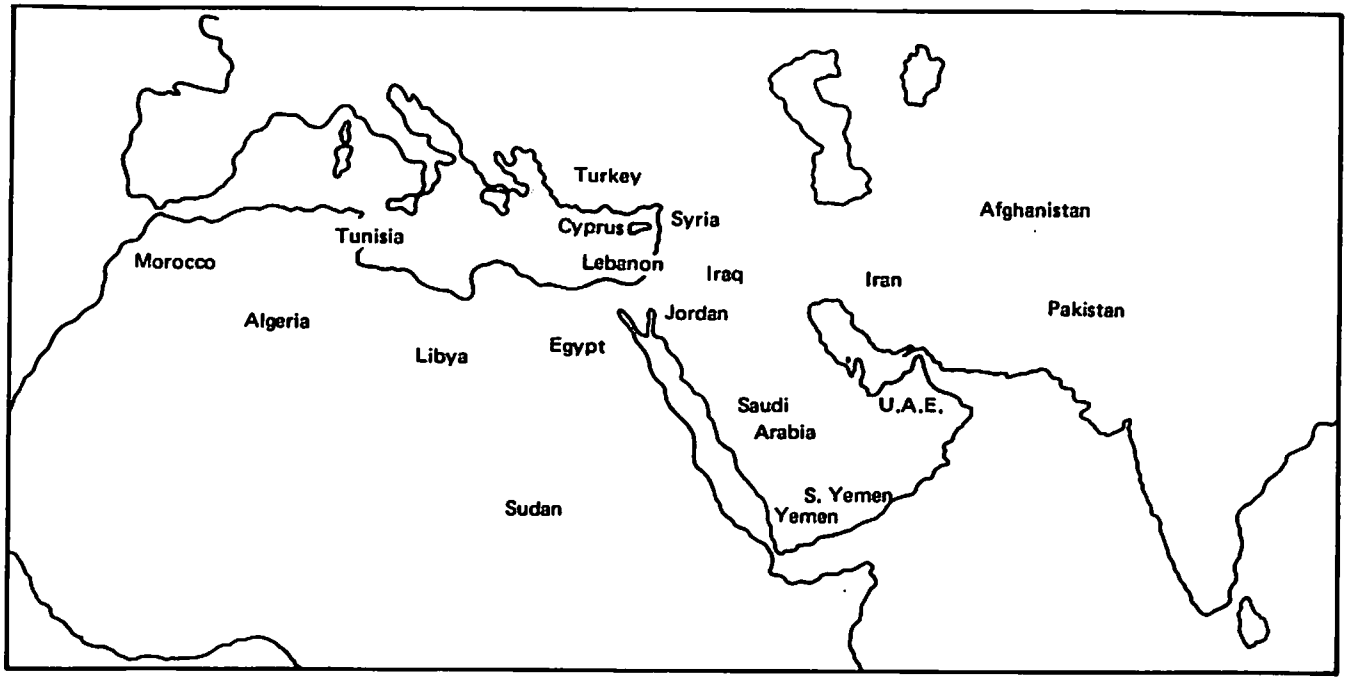

Fig. 1. The ICARDA region.

Table 1. Factors affecting seed production in different countries (for winter cereal, food legume, and forage crops).

Country	Factor							
	Disease	Insects	Improved seed availability*	Seed price	Laboratory processing	Trained manpower	Labor	Effective seed laws
Afghanistan	Yes	No	Yes	NA	Yes	Yes	No	Yes
Algeria	Yes	No	Yes	Yes	No	No	Yes	Yes
Bangladesh	Yes	Yes	Yes	Yes	Yes	No	No	NA
Cyprus	Yes	Yes	No	No	No	No	Yes	Yes
Egypt	Yes	Yes	No	NA	No	No	No	NA
India	Yes	Yes	No	No	No	No	No	Yes
Iran	Yes	No	Yes	No	Yes	Yes	Yes	No
Iraq	Yes	No	Yes	NA	No	Yes	Yes	NA
Jordan	No	No	No	No	No	Yes	Yes	No
Lebanon	Yes	No	Yes	No	Yes	Yes	Yes	No
Libya	Yes	Yes	No	No	No	Yes	Yes	Yes
Morocco	Yes	Yes	Yes	Yes	No	No	No	Yes
Pakistan	Yes	Yes	No	Yes	No	No	No	Yes
Saudi Arabia	No	Yes	Yes	No	No	Yes	Yes	No
Sudan	No	Yes	Yes	Yes	No	No	No	No
Syria	Yes	No	Yes	No	No	Yes	No	No
Tunisia	Yes	No	No	Yes	No	Yes	No	Yes
Turkey	Yes	No	No	No	Yes	Yes	No	NA
Yemen A.R.	Yes	Yes	Yes	No	Yes	Yes	No	No
Yemen P.D.R.	Yes	No	Yes					

*In many countries, improved wheat seed is available.
NA = not available.

Table 2. Present status of seed industry facilities for winter cereal, food legume, and forage crops.

Country	Facility							
	Testing lab	Processing	Storage	Trained personnel	Transportation network	Marketing	Field inspection	Credit
Afghanistan	*	*	*	*	*	*	*	*
Algeria	0	0	*	*	0	*	0	0
Bangladesh	*	*	*	*	*	*	0	*
Cyprus	0	0	*	0	0	0	0	0
Egypt	NA	*	NA	0	0	*	0	*
India	0	0	*	0	0	*	0	*
Iran	*	*	*	*	*	*	0	0
Jordan	*	0	0	*	*	*	*	0
Lebanon	*	*	*	*	0	*	*	0
Libya	*	0	NA	*	*	0	NA	NA
Morocco	0	0	*	*	*	*	0	0
Pakistan	0	*	*	0	*	0	0	*
Saudi Arabia	0	0	0	*	0	*	*	0
Sudan	0	0	*	*	0	*	0	*
Syria	*	0	*	*	0	0	*	0
Tunisia	0	0	*	*	*	0	*	0
Turkey	*	*	NA	*	NA	*	NA	NA
Yemen A.R.	*	*	*	*	0	0	*	*
Yemen P.D.R.	0	0	*	0	*	*	*	*

0 = Adequate
* Needs improvement
NA = Information not available

Table 3. Seed production infrastructure (primarily for wheat) in the ICARDA region.

Country	Institutions			Seed production						
	Breeding	Varietal testing	Release	N	F	C	Certification agency	Processing	Testing lab	Distribution
Afghanistan	*	*	*	*	*	*	NA	*	*	NA
Algeria	*	*	*	*	*	*	*	*	*	*
Bangladesh	*	*	*	*	*	*	*	:A	*	*
Cyprus	*	*	*	*	*	*	*	‹	*	*
Egypt	*	*	*	*	*	*	*	*	*	*
India	*	*	*	*	*	*	*	*	*	*
Iran	*	*	*	*	*	*	*	*	*	*
Iraq	*	*	*	*	*	*	NA	*	*	NA
Jordan	*	*	*	*	*	*	*	*	*	*
Lebanon	*	*	*	*	*	*	NA	*	NA	*
Libya	*	*	*	*	*	*	*	*	*	NA
Morocco	*	*	*	*	*	*	*	*	*	*
Pakistan	*	*	*	*	*	*	*	*	*	*
Saudi Arabia	*	*	*	-	-	*	-	*	-	*
Sudan	*	*	*	*	*	*	*	*	*	*
Syria	*	*	*	*	*	*	*	*	*	*
Tunisia	*	*	*	*	*	*	*	*	*	*
Turkey	*	*	*	*	*	*	-	-	-	-
Yemen A.R.	-	*	*	*	*	*	-	*	-	*
Yemen P.D.R.	*	*	-	*	*	-	-	-	-	-

* = Exist
- = Non-existent
NA = Information not available
N = Nucleus

Table 4. Developmental stage of seed production in 21 countries.

Country	Wheat				Barley				Forage				Food legumes			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Afghanistan			●					●				●				●
Algeria	●					●					●				●	
Bangladesh		●						●				●				●
Cyprus	●				●					●				●		
Egypt	●						●			●					●	
India	●					●				●				●		
Iran	●						●					●				●
Iraq		●				●						●				●
Jordan		●					●					●				●
Lebanon		●										●				●
Libya		●					●				●					NA
Morocco	●					●					●				●	
Pakistan		●						●				●		●		
Saudi Arabia		●						●								●
Sudan		●						●		●					●	
Syria	●					●						●			●	
Tunisia	●					●					●				●	
Turkey		●					●			●					●	
Yemen A.R.		●						●			●					●
Yemen P.D.R.		●						●				●			●	

1. Developed
2. Semi-developed
3. Poorly-developed
4. Non-existent

NA = Not available

Table 5. Proportion of seed requirements (%) met by existing facilities.

Country	Bread wheat	Durum wheat	Barley	Forage	Chick-pea	Faba bean	Lentil
Afghanistan	N	N	0	0	N	0	N
Algeria	50	50	30	10	N	N	10
Bangladesh	N	0	0	0	N	0	N
Cyprus	60	45	60	60	0	0	0
Egypt	70	60	NA	NA	N	NA	NA
India	25	10	N	N	N	0	N
Iran	N	N	0	0	0	0	0
Iraq	20	10	N	0	0	0	0
Jordan	N	40	N	0	0	0	0
Lebanon	25	25	10	0	0	0	0
Libya	60	40	60	N	N	N	0
Morocco	70	30	10	N	N	N	N
Pakistan	10	0	N	N	5	0	N
Syria	40	40	N	0	N	0	0
Saudi Arabia	60	0	0	0	0	0	0
Sudan	50	-	-	5	0	8	0
Tunisia	70	70	10	70	0	10	0
Turkey	NA	NA	N	N	N	N	N
Yemen A.R.	25	0	0	N	0	N	0
Yemen P.D.R.	40	N	0	0	0	0	0

N = Negligible
0 = Non-existent
NA = Information not available

Table 6. Total area under wheat and estimated seed requirements.

Country	Area[1] (1000 ha)	Certified seed requirements (1000 tonnes)[2]		
		Annual	5-year replacement	10-year replacement
Afghanistan	2400	240	48	24
Algeria	1700	170	34	17
Bangladesh	265	27	5	3
Cyprus	29	3	0.6	0.3
Egypt	584	58	12	6
Iran	4550	455	91	46
Iraq	1750	175	35	18
India	22220	2222	444	222
Jordan	94	9	2	1
Lebanon	50	5	1	0.5
Libya	340	34	7	3
Morocco	1656	166	33	17
Nepal	356	36	7	4
Oman	2	0.2	0.04	0.02
Pakistan	6696	670	134	67
Saudi Arabia	85	9	2	0.9
Sudan	248	25	5	3
Syria	1441	144	29	14
Tunisia	1134	113	23	12
Turkey	9300	930	186	93
Yemen A.R.	75	8	2	1
Yemen P.D.R.	15	2	0.4	0.2
Total	54990	5501	1101	553

[1] From FAO Production Yearbook, Vol. 33, 1979.
[2] Seed rate 100 kg/ha.

Table 7. Total area under barley and estimated seed requirements.

Country	Area[1] (1000 ha)	Certified seed requirements (1000 tonnes)[2]		
		Annual	5 year replacement	10 year replacement
Afghanistan	320	32	6	3
Algeria	800	80	16	8
Bangladesh	20	2	0.5	0.25
Cyprus	40	4	1	0.5
Egypt	45	5	1	0.5
Iran	1200	120	24	12
Iraq	920	92	18	9
India	1836	184	37	19
Jordan	42	4	1	0.5
Lebanon	5	0.5	0.1	0.05
Libya	450	45	9	5
Morocco	2193	219	44	22
Nepal	26	3	0.6	0.3
Pakistan	177	18	4	2
Saudi Arabia	13	1	0.2	0.1
Syria	1102	110	22	11
Tunisia	642	64	13	7
Turkey	2750	275	55	28
Yemen A.R.	65	7	1	0.5
Yemen P.D.R.	2	0.2	0.04	0.02
Total	12648	1265	258	129

[1] From FAO Production Yearbook, Vol 33, 1979.
[2] Seed rate 100 kg/ha.

Table 8. Total area under pulses[1] and estimated seed requirements.

Country	Area[3] (1000 ha)	Certified seed requirements (1000 tonnes)[2]		
		Annual	5-year replacement	10-year replacement
Afghanistan	35	4	1	0.5
Algeria	111	11	2	1
Bangladesh	361	36	7	4
Cyprus	8	1	0.2	0.1
Egypt	149	15	3	3
Iraq	52	5	1	0.5
India	23429	2343	469	234
Jordan	18	2	0.4	0.2
Lebanon	13	1	0.2	0.1
Libya	8	1	0.2	0.1
Morocco	434	43	9	4
Nepal	112	11	2	1
Pakistan	1687	169	34	17
Saudi Arabia	4	0.4	0.1	0.05
Sudan	76	8	2	0.8
Syria	230	23	5	2
Tunisia	152	15	3	2
Turkey	694	69	14	7
Yemen A.R.	84	8	2	1
Total	27657	2765	582	277

[1] Chickpea, faba bean, pea, lentil, and other beans.
[2] For simplicity the average seed rate has been taken as 100 kg/ha.
[3] From FAO Production Yearbook, Vol. 33, 1979.

Table 9. Total area under chickpea and estimated seed requirements.

Country	Area* (1000 ha)	Certified seed requirements (1000 tonnes)		
		Annual	5-year replacement	10-year replacement
Algeria	42	4	1	0.5
Bangladesh	56	6	1	0.6
Cyprus	1	0.1	0.02	0.01
Egypt	6	0.6	0.12	0.06
Iran	39	4	1	0.4
Iraq	14	1	0.2	0.1
India	7871	787	157	79
Jordan	1	0.1	0.02	0.01
Lebanon	1	0.1	0.02	0.01
Morocco	62	6	1	0.6
Nepal	68	7	1	0.7
Pakistan	1224	122	14	7
Sudan	3	0.3	0.06	0.03
Syria	47	5	1	0.5
Tunisia	37	4	1	0.4
Turkey	180	18	4	2
Total	9652	965	182	92

* From FAO Production Yearbook, Vol 33, 1979.

Table 10. Total area under lentil and estimated seed requirements.

Country	Area* (1000 ha)	Certified seed requirements (1000 tonnes)		
		Annual	5-year replacement	10-year replacement
Algeria	16	2	0.4	0.2
Bangladesh	85	9	2	1.0
Egypt	9	1	0.2	0.1
Iran	35	4	1	0.5
Iraq	10	1	0.2	0.1
India	925	93	19	9
Jordan	12	1	0.2	0.1
Lebanon	3	0.3	0.06	0.03
Morocco	29	3	0.6	0.3
Pakistan	106	11	2	1
Syria	89	9	2	1
Tunisia	3	0.3	0.06	0.03
Turkey	200	20	4	2
Total	1522	155	32	15

* From FAO Production Yearbook, Vol. 33, 1979.

Seed Program Components

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Introduction

A seed program is a complex and integrated organizational concept which can be defined as "an outline of measures to be implemented and activities to be carried out to secure the timely production and supply of seeds of prescribed quality in the required quantity" (Feistritzer and Kelly 1978).

A comprehensive seed program has several essential components (Fig. 1) which are strongly interrelated. The most important of these are: variety breeding, evaluation, and release; seed multiplication; processing and storage; seed quality control; and marketing and distribution. Each stage must be implemented at the proper time and in the correct sequence. If one component is not operative, the entire seed program will not work properly. A highly sophisticated seed quality control service, for example, is useless if the seed processing plants are poorly designed and unable to produce high quality seed.

Breeding

A sound seed program must be supported by strong breeding activities. The production of quality seed of traditional varieties seldom generates sufficient benefits to the farmer to compensate for the increased cost of the seed. The breeding program for a new variety produces small quantities of what is called breeder seed. This seed is the parent material for further multiplication, and the source of all certified seed.

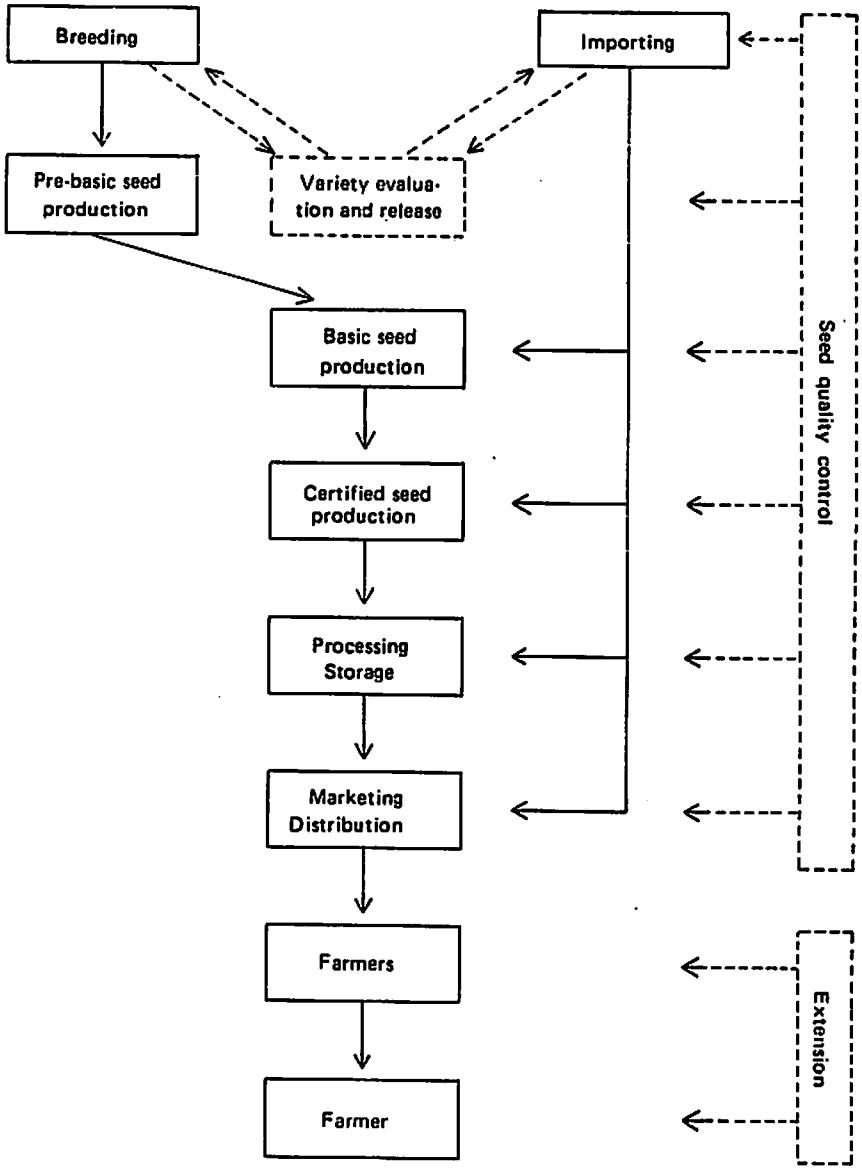

Fig. 1. Seed flow.*

*Source: van Amstel, H. and van Gastel, A.J.G. 1985. Seed programmes for ACP countries: present situation and future prospects. Seed seminar, 21-25 Oct 1985, Yaounde, Camaroon.

A country can also obtain new varieties from abroad. In fact, at the initial stages of seed program development, varieties often originate from screening international collections in national trials. Imported seed (either basic or ready-to-use certified seed) is another alternative. At later stages, the national breeding programs will develop the new varieties for the country, at least those of basic food crops.

Variety testing

A proper system should be established to evaluate new varieties before they are released to farmers. Varieties are usually evaluated in field tests for about three years. In such experiments, which should be conducted in the various ecological zones of the country, the agricultural value of new varieties is compared with that of existing ones. If possible, such experiments should be carried out under different farming systems.

When the number of varieties increases and the program advances beyond the initial stage, accurate variety description is required, particularly when seed certification or a system of plant breeders' rights must be implemented. Varietal description is also necessary for consumer protection. Therefore, in addition to agro-ecological value, varieties are also tested for distinctness, uniformity, and stability (DUS tests).

Variety release

Governments wish to have some control over the varieties multiplied in order to ensure that only superior varieties are grown in the country. A national variety release committee often advises on release based on the results of performance trials and DUS tests.

Maintenance breeding

The purpose of maintenance breeding is to produce new lots of breeder seed with the same genetic composition. It is the breeder's task to maintain the variety once it has been released. For cereals, plants representing the variety are grown in ear-rows and very carefully observed. Plants from selected rows are harvested and grown in small plots. The best plots produce the breeder seed, which should be very pure, because poor maintenance is difficult to correct later on.

Plant breeder's rights (PBR)

To protect the investments of plant breeders in the development of new varieties, many countries with developed seed industries have adopted PBR, granting proprietary rights to the breeder of a new variety. The breeder's authorization is needed for multiplication and a license fee or royalty must be paid to him. PBR systems have been adopted mainly in countries where many private breeders are involved in developing new varieties. In countries with publicly-financed breeding, such systems are less appropriate.

Seed Multiplication

The small amount of breeder seed is multiplied a number of times to produce the large quantities of certified seed needed to satisfy farmers' requirements.

The breeder seed is first multiplied to produce basic seed; this in turn is used to produce certified or commercial seed. The quantity of seed and the acreages in the different classes increase at each step. The number of cycles in each class depends on the stability of the crop, the risk of diseases, the multiplication rate, and the final amount of seed required. Throughout the multiplication cycles, a high level of purity should be sustained to guarantee a high quality end product. The standards for early generations are slightly higher than for later generations.

To prevent genetic changes, the early generations should be grown in areas to which the variety is adapted. No selection should be attempted, other than roguing off-types, and the best possible agricultural practices and inputs should be applied.

Processing and Storage

Careful processing is very important in producing quality seed. This step is the most capital-intensive component of the seed program.

All seed requires processing; the seed is dried, cleaned, graded, sized, blended, treated, and packaged. The entire process is a complex, largely mechanized operation using relatively sophisticated equipment.

The processed seed is stored in specially constructed seed stores protected against damaging environmental conditions such as high temperature and seed moisture content, under which viability rapidly deteriorates. In the humid tropics where conditions are particularly unfavorable for seed storage, the investment in drying equipment and seed stores can be very high.

Marketing

Marketing is vital for improved varieties to reach the farmer. The seed should be of the right quality and available at the right time, in the required quantities, and at a reasonable price. All required inputs must also be available.

In countries with a developed seed program and a strong private seed sector, certified seed is distributed to the farmers through a highly organized and effective distribution network, involving wholesalers and retailers. Such an organization, which takes many years to evolve, also promotes sale of seed and helps to forecast accurate market demand, which is essential for production planning. The success of a distribution network depends largely on the selection of competent retail dealers.

In many developing countries without a private organized network, seed is usually distributed through a public supply system. Effective, efficient distribution is often one of the main constraints in getting the improved seed to the farmer.

Seed Quality Control

The seed quality control service is a central unit which carries out checks at most stages to ensure high quality seed. Such an agency should not be linked directly to the organizations performing the other steps, but rather function as an independent governmental or semi-governmental organization directly responsible to the country's ministry of agriculture.

Seed quality includes purity, germination, health, weed seed content, moisture content, and other characteristics. Quality control is carried out through testing, certification, and legislation.

Seed testing

Seed testing is often the first step in enhancing the quality of the seed. The testing can be minimal (only for germination), or very extensive (for moisture, purity, germination, health, and other characteristics). Either one national or several regional testing stations can be established. Countries should follow the procedures of the International Seed Testing Association to facilitate ISTA membership at a later stage.

Seed certification

Seed certification ensures that the seed sold to the farmers is of the indicated variety, sufficiently pure, of good germination capacity, and disease-free. Certification steps include:

- *Field inspection* to verify seed source, varietal identity, previous cropping, isolation distance, impurities (off-types, weeds, other crops, and/or varieties), and diseases. In many certification schemes, the field inspector also estimates the yield and checks cultural practices.

- *Seed inspection* at the processing plant and in the seed store. Seed samples are taken and tested at the seed testing laboratory.

- *Pre- and/or post-control plots* grown on the farm of the certification agency to allow additional verification of varietal identity, varietal purity, and seed-borne diseases. Pre-control plots are grown in the same season as the main seed field and results are used for certification. Post-control plots, grown from seed that is already certified, function as checks on the effectiveness of field inspection.

Seed legislation

The quality of seed is more difficult to judge than that of any other commodity. Seed with very poor germination capacity, for example, may appear good. If such seed is planted, the farmer loses both his investment in the sowing seed and the entire value of the expected harvest. Seed legislation therefore regulates the various steps of the seed program to protect the farmer, using one of two different regulatory mechanisms:

- *Minimum standards*: specified for all seed allowed in trade. Substandard seed is excluded from the market. This approach is often used in countries whose farmers are not sufficiently educated.
- *Truth-in-labelling*: all seed is allowed to be marketed, but the quality is indicated on the label. The truth of the label is ensured by the quality control agency.

Generally speaking, it is not advisable to regulate all aspects of a seed industry in the early stages of development, nor should seed quality standards be set so high as to cause a seed shortage.

Other Considerations

A successful seed industry also depends upon outreach mechanisms such as extension--the education of farmers in the benefit and use of improved seed. Often, a system of credit facilities must also be established to enable farmers to purchase improved seed and complementary inputs. It is also important that markets exist to absorb the increased yields resulting from the new seed.

Acknowledgement

Most of the information in this chapter is taken from the paper by H. van Amstel and A.J.G. van Gastel, Seed programmes for ACP countries: present situation and future prospects. Seed seminar, 21-25 Oct 1985, Yaounde, Cameroon.

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Organizing and Managing a Seed Production Program

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Introduction

Seed is the first link in the food production chain, and carries the genetic potential for higher crop production. The first step in developing a seed program is to assess the existing situation: the present seed production of various crops, seed import and export, supply to farmers, availability of trained personnel, agricultural organizations, and seed production potential. Subsequent evaluation and guideline-setting are also important.

Crop Research

Breeding of new varieties is the basis of a seed program, but research on cultural practices (plowing, fertilizing, planting density, weed control, and harvesting) is also essential. Farmers must then be convinced through field demonstrations to accept the new varieties and practices.

The breeder must maintain the purity of a variety, sometimes in partnership with a basic seed organization which further multiplies the breeder seed. A seed processing plant must be established to handle both small seed lots and larger quantities of basic seed. The number of multiplications from breeder seed depends on the seed program's stage of development and upon the type of crop. Basic seed is then multiplied to produce certified seed.

To increase the seed production capacity from a seed program's initial stage requires persistent effort to generate interest among all involved. Public and/or private seed enterprises should be established. These can take various forms, including family operations, partnerships, cooperatives, companies, or corporations, depending upon national policy and the scope of seed production activities. Each program must be developed in the context of local conditions and potential, taking into account the demand for seed, availability of varieties, type of crops, ecological and other conditions for seed growing, availability of farmers/seed growers, methods of harvest, processing and storage, and seed supply to farmers.

Establishing a seed enterprise is but a first step. On-going management must take into account several factors including dependence upon weather conditions, seasonal nature of the work, timing and sequence of activities, and providing extension information to seed growers. Personnel must be trained in managerial and technical skills, including specialized staff for different tasks in large seed enterprises.

A seed enterprise may have its own farms for seed production and/or produce seed through contract growing. The seed organization must ensure that the contract grower receives adequate compensation, with the level of the premium above a commercial crop set by contract.

Seed Production Risks

Risks of seed growers: A grower expects an economical return; if the crop fails, he may be less inclined to start again the next season. Planning to eliminate some of the risks should include the following activities:

- Provision of viable and disease-free basic seed.
- Choice of a suitable seed production area.
- Selection of farmers genuinely interested in seed production.
- Insuring that equipment for land preparation, crop husbandry, harvesting, and drying is available.
- Furnishing trained staff to guide the seed grower.
- Provision of adequate compensation for the grower, in line with the price of commercial crops.
- Compensation for the grower to some extent in the case of crop failure, particularly for a new crop or variety.

Risks of a central organization or seed company:

- Seed supply: Once a market has been developed, a steady seed supply is important: if shortages occur, the organization may lose

credibility. Oversupply should also be avoided: adequate storage facilities can help, but the additional cost must be taken into consideration.

- Financing: In the planning stage, funds are required for capital inputs (building, machinery, transport, and equipment), as well as for "working" capital (for running expenses and for purchase of seed and other raw materials). The cost of capital inputs can usually be estimated fairly accurately, but care should be taken not to over-capitalize in early stages to enable a reasonable return on capital employed.

Profitability

In a well-functioning seed enterprise, the seed grower, the seed organization or company, the seed distributors, and the farmer should all make a profit. The cost of good seed is usually relatively low compared to the cost of other agricultural inputs such as fertilizer and equipment, so the seed organization should be economically viable or profitable.

No commercial organization can survive without making a profit, if profit is considered the money required to cover future costs. In a state-owned and/or private organization, the manager's task is to ensure that the organization will continue to serve its purpose in the future. The most efficient way is to make a profit, which can be calculated in several ways, commonly as return on capital employed.

Risks in Defining Seed Demand

Many factors influence the ultimate demand for seed in a given year as well as over the long-term. Overproduction, in which actual demand is lower than estimated, can be caused by several factors, including seed distribution problems, the switch of farmers to other crops which have suddenly become more profitable, marketing problems with the final product, and unrealistic estimates. A seed organization's management must be alert to changes in the trend of demand.

Underproduction, or seed shortage, can be caused by a number of factors. The farmers' response to new introduced seed may be greater than estimated, or unfavorable growing conditions can reduce the expected seed yield. Inadequate harvesting equipment might result in large harvest losses, and poor storage facilities can lead to storage

losses. Initially inadequate compensation of seed growers can lead to future difficulties in finding good growers.

Slight seed shortages often may be more financially beneficial than surpluses, but substantial shortages should be avoided as much as possible, because they can seriously affect the country's food situation.

One of the most hazardous exercises in the seed industry is defining future demand, which can be estimated as minimum, medium, or maximum:

	Minimum	Medium	Maximum	
Seed to be sold	x	x	x	kg
Seed to stock	y	y	y	kg
Seed to be produced	z	z	z	kg

The management must decide upon the acceptable amount of variation from each total. Defining demand is more difficult in a new organization than in a concern that has operated for many years. Estimates of future demand should take into account the following factors:

Basic seed reserves: There should be a strategic reserve of one season's supply of basic seed to ensure against unforeseen disasters during the growing season. Shortage of basic seed can jeopardize the entire seed production effort.

Unreliable rainfall: When a seed crop is grown in an area with unreliable rainfall and without irrigation facilities, a higher margin should be allowed than under more reliable conditions.

Available storage: Good storage facilities ensure a more certain seed supply than do poor facilities in which seed quickly deteriorates.

Seed characteristics: If seed cannot be stored for a long period, it is important not to overproduce, and to aim for a "planned shortage." Some crop species, however, produce seed that remains dormant and requires a certain storage period before it can be sold.

Seed Marketing and Distribution Channels

Seed marketing--a key task in improving seed supply--must include extension and demonstration plots: sales promotion and selection of sales storage sites: seed distribution, including transport; education of dealers (wholesale and retail); financing arrangements, including credit; price negotiations; estimates of marketing cost; and post-sales market surveys.

Seed distribution has unique problems, since most seed is required at the beginning of the planting season when an abrupt peak in demand must be met. A serious marketing effort--an essential part of total production--requires specialized staff who can do follow-up visits during the off-season and prepare for the next season's distribution well in advance.

Variety Testing

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Introduction

The breeder initially evaluates new material at the breeding station. Such trials are often not sufficient and more experimental sites, located in different ecological zones, are required to obtain a reliable agronomic value for experimental varieties. In comprehensive seed programs, the final evaluation is usually carried out by a separate varietal evaluation agency. Varieties from different breeders are objectively compared with existing varieties at a large number of locations with a wide range of soils and climatic conditions.

The Varietal Evaluation Agency

In many countries, the variety evaluation agency is an independent governmental organization, charged with the final evaluation of new varieties before release. This agency's farm must be centrally located, and sited to represent the conditions in major growing areas. Many agencies have sub-stations or additional experimental farms.

Varieties are tested using two types of experiments: performance trials, and tests for distinctness, uniformity and stability (DUS).

Performance Trials

Performance trials aim to compare the agricultural value of new varieties with that of existing commercial varieties and to identify those that are superior in certain ecological zones. Varieties with wide adaptability are also identified. Varieties are commonly tested in three subsequent years.

Variety trials in the different agro-ecological zones are carried out by breeding stations, universities, agricultural schools, and training centers, and also in farmers' fields under the supervision of the varietal evaluation agency.

Preparation of samples

The varieties to be tested may come from different breeding institutions. To minimize the risk of differences in agricultural performance due to different pre-planting treatments, seeds for all locations should be prepared by the varietal evaluation agency. If seed treatment is needed, the agency should treat all seed before it is dispatched.

Experimental set-up

Performance trials require the selection of appropriate statistical designs as well as the proper size, shape, and number of replicates. The choice of experimental design depends mainly on the number of varieties to be tested. For a small number of varieties, a randomized block design can be used. If the number of varieties is large, more sophisticated experimental designs must be used, such as Latin squares or lattices.

When yielding ability must be assessed under different management schemes, such as various nitrogen levels or different cultural practices, a factorial or split plot design can be used. Statistical textbooks give complete explanations of these methods.

The varieties must also be grown with the same cultural practices used by the farmer to produce a commercial crop.

Field observation and scoring

For cereals and pulses, the most important character to assess is the yield (kgs) of grain per hectare (taking into account the moisture content of the crop). For pasture and forage crops, the total dry matter is the key character; the different quantities of dry matter

produced at different times throughout the year are valuable agronomic data. Grain yield is only of interest in this case for seed production purposes. In addition to yielding ability and dry matter production, data are recorded on other important agronomic characteristics.

Table 1 shows the characteristics recorded for wheat as an example. The same type of observations are made for other crops, but each crop has a number of specific characters to be recorded. Many characters are scored on a 1 to 9 scale, with 1 indicating the less desirable state and 9 the most desirable. A more sophisticated scoring system is often used for disease resistance.

Table 1. Characters recorded in field observation of wheat in performance trials.

Characters		
Frost resistance	Resistance to diseases and pests:	Lodging
Germination capacity	stripe or yellow rust	Drought resistance
Vigor	leaf or brown rust	Tolerance to salinity
Tillering	stem or black rust	Sprouting
Heading date	loose smut (*Ustilago*)	Shattering
Number of heads	covered smut or bunt (*Tilletia*)	Date of maturity
	Septoria	
	Fusarium	

Special tests

Special laboratory tests may also be done, depending on how the crop is used. For wheat milling properties, dough quality, baking quality, and thousand kernel weight are determined. For barley, beer making quality is assessed. Other crops have their own special tests. The variety evaluation agency does not carry out all such tests, but is assisted by other specialized organizations.

Statistical analysis and reporting

Extensive analysis is usually carried out only on the yield data. Each experimental design has its own method of statistical analysis. The method chosen, however, must allow analyses to be carried out over a number of locations within a year, as well as over different years. Since variety evaluation is a continuous process, with new promising varieties entered yearly in the experiments and other varieties

withdrawn upon completion of the three-year performance trial cycle, the method must be able to handle a changing number of entries. Computer facilities are often required.

To make the yield description more meaningful, yields are often expressed as a percentage of the yield of the control variety. This is done because a variety's yield varies at different locations in the same year, and in different years at the same location.

Many other characters are expressed on a 1 to 9 scale (see Table 2 for examples), with the higher number indicating the more desirable state, or by abbreviations, with each abbreviation representing the status of a character (for example, la=late maturing, me=medium maturing, er=early maturing).

Table 2. Examples of scoring for three characters.

Character	Score				
	1	3	5	7	9
Presence of anthocyanin	absent				present
Intensity of anthocyanin color	absent or very weak	weak	medium	strong	very strong
Plant growth	erect		intermediate		prostrate

DUS Tests

Distinctness, uniformity, and stability (DUS) tests are conducted to establish whether or not a variety is sufficiently distinct from all other varieties, and sufficiently uniform and stable. Based on DUS tests, a variety description is produced that is often used for field inspections and granting proprietary rights.

Distinctness: This quality is essential because a new variety must be different from an existing variety. Each variety must be recognizable not only in field inspection, but also for seed growers and farmers who want to grow a specific variety. For granting proprietary rights (Plant Breeder's Rights), the variety must be clearly recognizable.

The distinctness may be morphological, physiological, cytological, or chemical. A clear morphological distinction is obviously preferable but not always possible because of the large number of varieties available.

Uniformity: To guarantee constant quality and also for field inspection purposes, a variety must be as uniform as possible. The degree of uniformity depends on the mode of reproduction. Varieties of self-pollinated crops are more uniform than varieties of cross-pollinated crops. In a highly mechanized agricultural system in a region that is agriculturally and climatologically homogeneous, a high degree of uniformity may be desirable, but under other conditions, a certain degree of variability may be advantageous.

Stability: During the various stages of seed multiplication from breeder seed to certified seed, the variety should not lose its distinctive characters. The genetic make-up should remain as near as possible the same. Varieties of self-pollinated species are more stable than varieties of cross-pollinated species; hybrids are not stable, and new hybrid seed must be produced each year for farmers.

Experimental set-up

The DUS tests are carried out at the farm of the varietal evaluation agency. The farm's location should be representative of the major growing areas, because environmental conditions can influence the expression of the varietal characters.

The seeds to be tested should not be treated, because treatments can affect the expression of characters. The seeds are often planted by hand to minimize the risk of admixture. If possible, plants should not be sprayed for weed control but hand-weeded instead.

As far as experimental design is concerned, DUS plots usually have only two replications, since such a large number of observations must be made. Varieties are not planted randomly; instead, those varieties that closely resemble each other are planted adjacently.

DUS tests are carried out for two subsequent years. The breeder supplies new seed for each year, preferably from a next generation of breeder seed.

Field and laboratory observations

Distinctness, uniformity, and stability are studied on individual plants sown in small plots. A wide range of existing varieties is

usually available for comparison. During the growing period, careful observations are made on individual plants; after the crop has matured and ripened, elaborate scorings are made of ears, heads, and other parts, as well as of seeds in the laboratory. Such tests are often difficult, requiring considerable skill and time. More than 40 different characters may well be recorded in DUS tests.

A special method often used in DUS tests is the observation of the progenies of single ears. Progenies of 50 to 100 ears are grown in rows (ear-rows) and carefully observed. Any lack of uniformity is thus easily detected.

Further details on the characteristics to be scored can be found in publications of the International Union for the Protection of New Varieties of Plants (UPOV) and the Organization for Economic Cooperation and Development (OECD).*

Scoring

Either quantitative or qualitative characteristics may be used to distinguish varieties. Qualitative characteristics are recorded visually, whereas quantitative characteristics are measured. Many characters are scored on a 1 to 9 scale. Table 2 shows examples of scoring for three characters.

Statistical analysis

No straightforward statistical analysis is done on the data from DUS experiments; instead, the average scores are compared and conclusions drawn about distinctness. A clear and consistent difference in just one character can be sufficient to qualify a variety as distinct. For measured characteristics, a difference is considered sufficient if it is significant at the 1% level (LSD).

Uniformity is judged from the individual plant scores within a replicate and, to a certain extent, from the differences between the two replicates. For measured characteristics, the standard deviation is used. A variety is not considered homogeneous if its variance exceeds 1.6 times the average of the variance of the varieties used for comparison.

Stability is judged by comparing the data obtained in two consecutive years. It is usually assumed, however, that a uniform variety is also stable. If lack of uniformity or stability is so

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slight that it is not obvious during two years of tests, it is not considered significant.

Reporting

The final report is often brief, listing only the major differences between similar varieties, as well as stating that the variety is sufficiently distinct, uniform, and stable. More elaborate descriptions are always available upon request.

The Variety Release Committee

The test results are reviewed by the variety release committee, which is usually composed of six to eight persons representing organizations involved in the seed industry such as breeding institutes, seed multiplication organizations, seed firms, extension services, and farmers' organizations. The committee reviews the performance of existing and new varieties and makes recommendations for releases and withdrawals.

Variety Lists

In many countries variety lists are prepared each year to inform the farmer about the morphological and/or agronomic characteristics of the commercial varieties, including the latest releases. Information on cultural practices is often included as well. The list also indicates those varieties eligible for certification.

Variety lists can either be advisory or restrictive; in the latter case, seed trade is limited to the listed varieties.

Variety Release and Promotion of Quality Seed

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Introduction

Quality seed is one of the cheapest and most essential inputs for crop production. Most developing countries in West Asia and North Africa recognize the importance of seed production, but means and facilities are inadequate for effective seed production, quality control, distribution, marketing, variety evaluation, and release.

The main objective of a plant improvement program is to identify and produce new varieties capable of increasing production per unit area. These new cultivars should also have better defined characters than the existing cultivars. Their seed should be increased quickly and distributed to farmers. At the same time, old and improved cultivars should be compared in demonstration plots as to yielding ability, disease and pest resistance, earliness, consumer preference, quality requirements, and other desirable characteristics. A perfect cultivar with all desirable characteristics is very difficult to develop, so national programs should quickly adopt new cultivars that outyield local ones or have better qualities.

Plant improvement programs are organized differently in various countries, and new cultivars may be produced by governmental agencies, private companies, or individuals. Many of these countries control cultivar release by seed laws or regulations, while others give this responsibility to breeders. Western systems of variety release and seed production are often expensive and laborious for adoption by many developing countries; therefore, relatively cheap but technically sound systems must be developed for producing quality seed in the region.

Cultivar Release

Newly developed cultivars are released in different ways. Government agencies often regulate release, particularly in countries with private breeding programs, to protect farmers from new cultivars that are too similar to old ones, or have not been tested sufficiently. Such regulations also protect breeders against misuse of their new cultivars. In developing countries, where research organizations carry out most plant breeding, special release regulations are rare, but should be developed and implemented.

Before marketing a new cultivar, a breeder must test its qualities and assess its agricultural or horticultural value. Based on preliminary tests, breeders select their best lines for comparative trials, which are often done in different locations. When results are acceptable, the new cultivar can be multiplied in reasonable quantities and submitted for release. However, acceptance by farmers ultimately determines how widely the new cultivar will be used.

In comparing a new cultivar with established ones, the following criteria are used to decide whether or not seed should be multiplied and released for commercial planting:

Uniformity: The degree of varietal uniformity depends on the breeding systems employed. In pure lines, all individual plants can be identical, but such uniformity depends on the farming system for which the new cultivar is intended. If the new variety is aimed at a highly mechanized system in a homogeneous region, absolute uniformity within the new cultivar is ideal, but under other conditions, variability has some advantages. Although the standard of uniformity can vary for different species or even for different cultivars of the same species, it should be kept as high as possible. Examples of cases in which different purity standards are required are F_1 hybrids, pure lines, and composite and synthetic cultivars.

Varietal distinctness: The identity of the new cultivar and its distinctness from other cultivars are important characters which assist multiplication and certification. Distinctness may be based upon morphological, physiological, or agronomic characters; however, morphological distinction has the greatest practical value in maintaining a pure variety.

Stability: A stable cultivar should be able to reproduce itself over several generations without losing its distinctive identity. The degree of stability is influenced by the breeding system. Pure line cultivars are stable, but seed of an F_1 hybrid cultivar is completely unstable.

Value: The new cultivar must have suitable economic qualities or value.

For instance, wheat should be suited to bread-making needs, peas for canning, sunflower seed for oil, and forage for feed. Such values become increasingly important in a cash crop economy.

Agronomic performance: Unless the new cultivar is attractive to the farmer, it will not be grown to any extent. Performance includes characters such as yield per hectare, days to maturity, plant height, resistance to lodging, response to fertilizers, resistance to common diseases and pests, quality characteristics, and reaction to adverse environmental conditions such as drought, cold, and salinity.

Variety Release Committee

In developed as well as in most developing countries, the decision to register new cultivars is usually entrusted by law to an official committee, with members generally selected from official governmental agencies or institutes concerned with crop improvement. These individuals should be independent from the crop improvement specialists submitting new cultivars for release. It is important, however, that at least one member of the release committee has sufficient knowledge of crop improvement.

Variety release committees normally meet at regular periods to approve new cultivars after producers have submitted their applications. The committee has to evaluate different types of information, particularly the cultivar description and field trial results. The degree to which a release committee considers a breeder's evaluation differs from one system to another. Voluntary registration schemes often give great weight to the breeder's evaluation, while compulsory systems generally accept only official tests and methods. The release committees are also responsible for cultivar denomination, after considering the applicant's proposal.

Cultivar Denomination

The name of a new cultivar must be approved by the release committee, to prevent confusion with other cultivars. It is important that denominations are short, simple, and easy to remember. Names should not include descriptive elements referring to the quality of the new variety, since these often become outdated and also increase the risk of error and confusion, especially in translation.

The earlier procedure for using the breeder's name or trademark for cultivar denomination is no longer permitted for official registration in most countries. An international code of nomenclature for

cultivated plants was developed by a commission of the International Union of Biological Science, under the United Nations Educational, Scientific and Cultural Organization (UNESCO). This code governs the use of non-Latin names for cultivars within a botanically-named species. This system encourages uniform practice in naming cultivars through stating guiding principles and by making specific recommendations about the formation, use, and recognition of such names.

The code includes the following recommendations:

- Numerals and symbols should not be used as names (e.g., "S.23" perennial ryegrass).
- Names should not exaggerate the merits of a cultivar, as they may become inaccurate when new cultivars are introduced (e.g., "Earliest of all" tomato).
- Names should not consist of more than two words.
- Names should be simple, short, easily pronounced, and unlikely to be misspelled.
- After a cultivar stops being grown by farmers, its name should not be used for another cultivar for at least 10 years.

Promotion of Quality Seed

Utilization of quality seed is an essential factor in increasing agricultural production and farmers' net income. No one benefits from the time and money invested in developing quality seed of improved and high yielding cultivars, until farmers harvest a good crop from the seed.

Directors of seed programs should be aware of the factors that influence farmer acceptance and use of improved cultivars. These include:

Cultivar profitability: The degree to which farmers recognize that the improved seed or new cultivar will increase benefits, or reduce costs, compared to old seed or cultivars. This factor also encompasses the difference in efforts, risk, prestige, or social approval that may result from using the improved seed or cultivar.

Yield stability: The degree to which a farmer recognizes that the use of the new cultivar will consistently yield well, especially when he faces difficult environmental conditions.

Simplicity: The degree to which farmers recognize that the new cultivar's seed is easy to obtain, and also that associated growing practices are easy to use.

Compatibility: The degree to which a farmer recognizes that a new cultivar fits his needs, values, past experience, and available farming systems. As an example, a cultivar with an extremely long or short growth cycle might not fit into a farmer's cropping system or his community's cropping pattern. An inappropriate cycle might cause serious problems with the use of irrigation, pest control, access to labor for cultivation and harvest, or the availability and suitability of equipment for marketing, processing, or transportation.

Visibility: The degree to which a farmer can see the results of having utilized a new cultivar, and how apparent they are to others. A new cultivar with distinctly different growth characteristics will look better in the early stages than the old cultivar. Difference in quality and quantity of the yield should also be visible.

Limited risk: The degree to which farmers recognize that they can try a new innovation on a limited basis. The use of quality seed has a distinct advantage over some other innovations in that a farmer can usually limit his trial to a small fraction of land.

Independence: The degree to which farmers recognize that they can adopt the new innovation without consulting others. Unless landlords, credit institutions, or the community impose demands or restrictions, the decision to use seed of a new cultivar can be made independently. If the seed is readily available, farmers are generally free to choose to plant it. Many innovations may have a lesser degree of independence.

Heads of farmers' unions, progressive farmers, and directors of seed programs should establish communication with farmers and inform them about new seed. They should also develop a sound marketing system to provide farmers with the cultivars, while encouraging appropriate governmental policy.

The acceptance of new innovations such as seed of improved cultivars is strongly influenced by the availability of production inputs and access to markets for harvested crops. Setting specific goals, identifying the groups with whom communication is needed, and committing resources to stimulate action are important factors in formulating campaigns to introduce new cultivars and related technology.

Research activities on seed production should be linked to extension programs in order to effectively transfer appropriate technology to farmers. Increasingly, national and international organizations as well as seed enterprises are relying more and more on applied or adaptive research in farmers' fields. This technique makes it possible for farmers to participate and learn, and also motivates them to obtain seed of promising cultivars. Agronomists and extension workers also learn how to manage the new technology effectively.

Technical knowledge, scientific know-how, economic understanding, and farming ability should be strengthened for staff of research programs and extension services. Communication skills and successful campaigns also require adequate resources for staff training, a budget for salaries, operational and maintenance costs, travel costs, and personnel policies with incentives for encouraging staff.

An effective seed promotion program requires close cooperation between staff involved in research, extension, communication, seed enterprises, and marketing. No single group has a monopoly on communicating with farmers.

To determine the actual demand for seed, market research is required at both the national and the seed enterprise level. Market information is important for organizing production and marketing programs, while a seed enterprise can forecast market demand by what buyers, sellers, or experts say, do, and have done in the past.

Pricing procedures for seeds may differ widely from crop to crop, depending to a large extent on whether the farmer can save some of his own seed or not. Direct and indirect costs, profit, and an estimate of what buyers will pay should also be considered in pricing new seed. The economics of shipping or transporting the seed from the place of production to the place of use also requires close examination in planning marketing activities.

Government policy and action affect the use of seed. For example, a policy that permits seed prices to include all costs, as well as some opportunity for profit, should stimulate the growth of seed enterprises and marketing groups. Well-planned crop production campaigns can also stimulate the demand for quality seed.

To promote use of good seed, a vigorous seed extension program should be developed to advise farmers on the advantages of using controlled quality seed of improved cultivars. Such a program should lead to increased production and higher income for farmers, and overall benefits for the rural communities. The extension program should:

- Inform farmers of the existence and advantages of quality seed.
- Convince farmers to use quality seed on a large scale.
- Inform farmers about ways of getting quality seed and about related government policies.
- Train farmers in how to cultivate the seed.
- Establish an effective liaison between farmers, plant breeders, and seed production specialists.
- Organize field days and demonstration plots on farmers' fields.

Farmers and others can be informed about the new cultivars or quality seed through radio, television, and newspapers. Meetings should also be held between farmers, their leaders, seed specialists, and policy makers. Visits to field or demonstration plots can be organized, and field days can be held at villages, cities, and farmers' organizations. Visits to other successful seed programs within the

country or abroad should also be encouraged, and occasional specialized training courses held for farmers, seed specialists and policy makers.

Conclusion

Seed programs, a service to farmers, fulfill their function only when most farmers can easily obtain and plant quality seed. Seed production should be considered as only one component of a program's objectives; other components are development of stronger research capabilities, effective maintenance and multiplication of initial seed increases, and the establishment of effective seed enterprises, quality control systems, marketing mechanisms, and educational units. In the long run, these initiatives are successful when they foster growth in agricultural production and when seed of improved varieties can flow to farmers through an ever-expanding pipeline.

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The Organization of the Seed Industry in The Netherlands with Emphasis on Cereals

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Introduction

This paper describes the components of the Dutch seed industry and the links between them. The seven main steps or components, from the breeding of a new variety to its use by the farmer, are given in Fig. 1.

Most of the components of Holland's seed industry have evolved over a long time under specific conditions which may differ in other countries in the same stage of development. Over the last few decades, mainly because of extensive communication and trade with other countries, seed industries have begun to follow more or less standard international procedures, which are important for countries that wish to export seed. In such countries, varietal evaluation, and especially seed testing and labelling, should conform to international agreements. Holland's seed industry, described here, is only an example; each country must develop a system that fits its own climatological, ecological, and socio-political conditions.

Plant Breeding

Plant breeding in Holland has always been a private enterprise. For centuries, farmers did their own crop selection. Private or public breeding organizations later selected from already existing landraces, with further refinements in resistance, yield, homogeneity, and other characteristics, to produce new cultivars. The profession of breeding developed gradually in the 1920s, and progressed rapidly during the

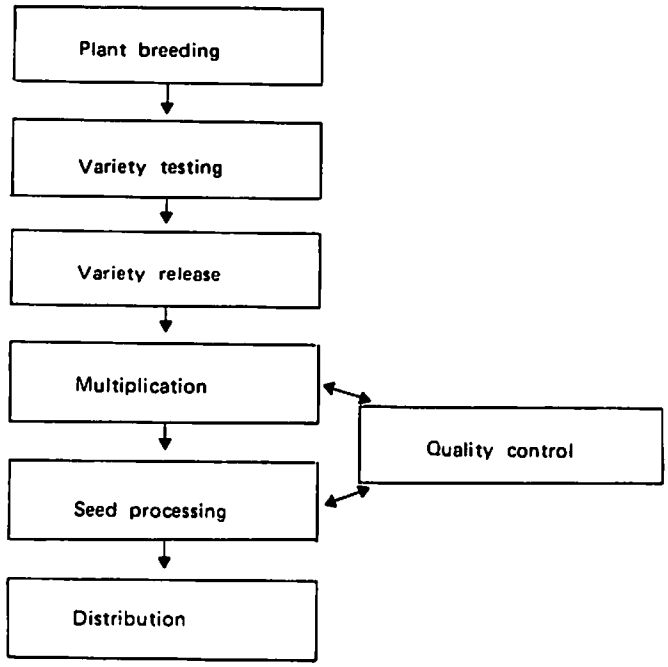

Fig. 1. The basic components of a seed industry.

1940s. The government has always supported private initiative through research by special institutes and the Agricultural University's breeding department. The Ministry of Agriculture also has two breeding institutes, one for arable crops and one for horticultural crops. Priorities for basic breeding research are set according to two considerations: general priorities in agricultural research; and needs of private breeding firms, farmers, and growers.

Basic breeding material with a new, highly-valued property such as a new resistance, but not yet stable in all its characters, is released to private breeding companies, which have the experience and facilities to breed true varieties to meet demand. The institutes and private companies regularly discuss the progress in breeding projects, with information kept confidential. When basic material is ready for release, the institute reports the material's background as well as the price and available quality of seed or plants. Such interaction ultimately benefits the farmers and growers.

Private companies are always under pressure to release basic material as soon as possible, while the institutes have the responsibility to prepare basic material up to the stage of development at which it can be taken over by the private breeder, and to ensure that no valuable material is lost.

Other institutes and experimental farms also contribute, often indirectly, to breeding programs. A phytopathological institute, for instance, provides sister institutes and private companies with infection material to enable breeding for disease resistance.

Varietal Testing and Release

A variety submitted by a breeder is not ready for multiplication and marketing until it has undergone extensive variety research. A farmer simply cannot carry out extensive comparative trials of many varieties; only government institutes, with trial farms throughout the country, can perform such evaluations to suit the various conditions of different farms (i.e., varieties appropriate for mechanized operations, different edaphic and climatological conditions, and different sowing and harvest times).

The proposed variety must also be established as an actual new variety. It must be subjected to botanical variety research for distinguishing characters; at least one character should be found to establish that it is a new, independent variety entitled to protection by "Plant Breeder's Rights" (which lasts 20 years for cereals). Based on distinguishability or identity, uniformity, and stability, the Board for Plant Breeder's Rights then registers the variety in the "Register of Varieties." Varieties considered valuable for growing in the Netherlands are put on the "List of Varieties."

For agricultural crops, the agricultural value must also be established, and must be better than that of already existing varieties in order to appear on the Variety List. This list is "binding" for agricultural crops, which means that only varieties on the list can be used commercially (with some exceptions for grasses and clovers, and for limited quantities of new varieties still undergoing varietal research; i.e., small-scale trials in practice). The list for horticultural crops, however, is not binding, so trade of unlisted varieties is possible. These lists also have an advisory function, especially for the crop grower. Varieties of horticultural crops listed on the so-called Common List of the European Economic Community can automatically be traded in all member states.

Multiplication, Processing, and Distribution

Private companies do the multiplication, processing, and distribution of seeds in Holland, so the government need not operate a separate seed distribution system. Every company, shop, or person

trading in seed, however, must be affiliated with one of four inspection services or certification authorities serving the various groups of crops: the General Netherlands Inspection Service (GNIS) for agricultural seeds and plants (NAK), the GNIS for vegetable and flower seeds (NAKG), the GNIS for ornamental plants (NAKS), and the GNIS for arboricultural produce (NAKB).

The inspection of cereals provides an example of these processes. The breeder is responsible for maintenance of the variety, so basic seed is produced under the breeder's responsibility on special multiplication farms. Varietal maintenance is controlled on the inspection service's central control farm through special pre-control plots of the generation before basic seed. There are two classes of basic seed (super elite and elite) and two classes of certified seed (first and second generation). In practice, second generation certified seed is produced, but used only if there is a shortage of first generation seed. (Table 1 gives seed certification terminology in Holland.)

Post-control is carried out on each certified lot of basic seed. The results are used as a pre-control for inspecting first generation certified seed. Field inspectors inspect pre-basic and basic seed fields twice, and certified seed fields once. For certified seed, post-control is random; approximately one lot in five is checked. For

Table 1. Cereal certification terminology in Holland.

Seed multiplier	Type of seed
Breeder	individual lines or clones breeder seed
Multiplication farm (under supervision of the breeder)	*pre-basic seed *basic seed
Contract growers	*certified seed, first generation *certified seed, second generation

*OECD terminology.

this system to work, careful administrative checking is necessary to control the origin of the propagating material, so an application form and all certificates of the seed used must be sent in by the farmer. All operations such as harvesting, storage, transport, and cleaning are supervised by the inspection service. Adequate regulations have been developed to safeguard the identity of the seed lots. During lot inspection and sampling, special attention is given to homogeneity; only uniform lots can be certified, and sampling is done according to the International Seed Testing Association (ISTA) Rules. When the lot meets the standards for moisture content, purity, germination capacity, health condition, etc., the lot is ready for certification. Labelling is done by the inspector or under his direct supervision. After sealing, the lots can be marketed.

Quality Control

Many aspects of quality control have already been discussed. Laboratory seed testing is another aspect; although part of seed certification, it also has some other functions (see Fig. 1). Because seed testing in Holland is done by only one institute, and performed according to the ISTA Rules, the procedures and regulations will not be detailed here.

Still another vital aspect of quality control is the advisory function of a seed testing station, whether in a new or an advanced seed industry. The advisory function may require more effort than the station's regular task of routine testing, particularly in a new seed industry. There may be many reasons for the industry's problems, including high temperatures, high moisture content, or even fraud, but major causes are usually ignorance and negligence. In many cases, the seed testing station can assist, through ad hoc applied research, in solving the "mystery" by checking the stages of production through germination tests before and after harvest, before and after drying, and at other stages.

Seed Industry Development in India

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Historical Background

In recent years, India has made rapid progress in seed production and technology. An early landmark was the first analysis of seed production needs and problems in India, in the 1928 report of the Royal Commission on Agriculture. In 1957, the Indian Council of Agricultural Research (ICAR) in collaboration with the Rockefeller Foundation introduced the All-India Coordinated Maize Project, marking the beginning of an intensive, integrated, and multidisciplinary approach to crop improvement in India. In 1960, ICAR started a similar project for sorghum and pearl millet, for which hybrids were released in 1964 and 1966, respectively. The complex seed production process needed for these hybrids demonstrated the inadequacy of the existing seed production system. The government of India decided to set up a seed corporation, and the National Seed Corporation (NSC) was incorporated in 1963 under the Companies Act by the government. The NSC was given responsibility for India's seed industry development, including the initiation of measures leading to the production, processing, and marketing of high quality seeds, particularly single crosses of hybrid maize.

The years 1963-69 saw rapid development of both the public and private industries in India. In 1965, the first 250 tonnes of dwarf wheat seed were imported from Mexico, followed by a bulk shipment of 18,000 tonnes in 1965. In the same year, the first dwarf paddy variety was imported from Taiwan, and in 1966, the Indian Parliament passed the Seeds Act.

Between 1963-69, the NSC was concerned mainly with foundation seed production. This period also saw certified seed production expand from about 360 ha to 35,000 ha. This production was concentrated in the private sector and in the Tarai Development Corporation, established in 1969 with World Bank assistance, and focused on the university, progressive farmers from the area, and the NSC. The project aimed at developing 16,000 ha for seed production, including 5,000 ha of the university farm. The main seed to be produced was wheat, with substantial amounts of paddy, maize, and soybean as well. This was the first attempt to develop a compact area for seed production. From the first year the Seed Act was enforced, the NSC functioned as the certification agency in all but one state. The NSC has also established a scientific seed processing industry in India and helped manufacturers to produce seed equipment locally.

The seed situation in India was reviewed in 1968 by the Seed Review Team and, in 1971, by the National Commission on Agriculture. The second review stressed the necessity of maintaining seed purity, considering the rapid deterioration of seeds of high-yielding varieties. In the light of various recommendations, the government decided to organize seed production agencies in different states of India so that seed support to planned crop production programs could be assured. These events are briefly summarized in Table 1.

Table 1. Summary of seed production and technology development in India.

1928	Royal Commission on Agriculture Report submitted, citing that facilities for increasing the supply of breeder seed were inadequate, and that varietal purity of seeds was not maintained.
1957	All-India Coordinated Maize Improvement Project began.
1960	Similar projects on sorghum and pearl millet began. Training in seed technology started.
1961	Four maize hybrids released.
1963	National Seeds Cooperation established.

1964	First sorghum hybrid released.
1965	First pearl millet hybrid released. 250 tonnes of dwarf wheat seed imported from CIMMYT, Mexico.
1966	Seeds Act passed (came into force in 1969).
1963-69	Certified seed production increased from 360 ha to 35,000 ha.
1968	Seed review team report submitted.
1969	Tarai Development Corporation established with World Bank assistance primarily to produce certified wheat seed. Concept of compact area development for seed production initiated.
1971	National Commission on Agriculture submitted its report. Government decided to reorganize seed production in India. The Indian Society of Seed Technology (ISST) was born.
1972	ISST organized first All-India Seed Seminar. (Five more have since been held.)
1975	Project Report on National Seeds Program (NSP) submitted.
1981	First workshop on seed technology under NSP was held. Certified seed production increased from 137,000 tonnes in 1974/75 to about 350,000 in tonnes in 1980/81.

The Seeds Act and Quality Control

The Seeds Act, passed in 1966, came into operation in October, 1969. The act and the subsequent rules established that seed of notified varieties of crops could be sold, offered for sale, or exhibited for sale only if they conformed to certain minimum standards of germination and purity laid down by the central seed committee.

Seed certification in India is linked with notification of variety, although variety release is not sufficient for certification. The responsibility of notification rests with the Central Seed Committee, which also sets minimum standards for certification. Such standards have been fixed for various crops and detailed methods for field inspection have been published in two booklets: "Minimum Seed Certification Standards" and "Field Inspection Manual." The government has established a central seed certification board to help state governments in seed quality control and legislation.

All state governments have set up one or more state seed testing laboratories. Out of 51 such laboratories in India, 32 have been designated as official seed testing laboratories. The number of seed samples they have tested rose from 65,000 in 1967 to 286,968 in 1982. A central seed testing laboratory has also been established. The laboratories' function is to check the seed standard for certification under the act. Seed certification is voluntary, but truthful labelling is compulsory.

Nonetheless, most seeds produced in India are certified, except for vegetable seeds which are truthfully labelled. The generation system of seed production is followed. For hybrids, and when rapid deterioration of varieties is expected, the generation system is: Breeder --> Foundation --> Certified. In highly self-pollinated crops, the system is: Breeder --> Foundation I--> Foundation II--> Certified I--> Certified II--> Certified III. Steps in the production of quality seeds in highly self-pollinated crops such as wheat and barley are shown in Table 2.

Production of Breeder and Foundation/Basic Seed

Production of the state and/or local varieties is the responsibility of the state universities and the state seed corporations, while foundation seed of the national and/or regional varieties, which is certified, is produced by the NSC.

Because breeder seed is not certified, its quality is monitored through field inspection by a team consisting of the crop coordinator, the breeder, and the NSC representative. The responsibility for the production of breeder seed rests with ICAR. Breeder seed thus produced is handed over to the national seeds corporation/state seed producing agencies for further multiplication.

Table 2. Relationship between plant improvement and seed production in a highly self-pollinated crop.

1. Plant Improvement	2. Seed Production
Variety development (breeding, introduction, etc.)	Breeder seed
New variety	
All-India Crop Improvement Project	Foundation seed stage I (seed certification and quality control)
Testing of varieties	Foundation seed stage II
Variety release	Certified seed stage I
Variety notification (makes a variety eligible for certification)	Certified seed stage II
	Certified seed stage III (not eligible for further certification)

Certified Seed/Quality Seed Production

The production of certified seed is increasing in India. This increase was modest up to 1978/79 (only five-fold compared to 1953/54), but later became spectacular, and the quantity of certified/quality seed produced in the country had increased about 31 times by 1983/84. It was projected that by the end of 1984/85 this increase would grow to about 40-fold as shown in Table 3.

The National Seed Programme

Because of the increasing demand for and production of certified/quality seed, the government launched the National Seed Programme (NSP) in 1976 with World Bank assistance (US$ 41 million, Government of India contribution RS 102.5 million; RS 10.0 = US$ 1.0) which provides for breeder seed production, seed technology research, and training and technical assistance (consultancy) for seed technology.

Table 3. Actual and projected increase of seed sold in India.

Year	Quantity of seeds sold (in thousand quintals)
1953/54	183
1978/79	903
1979/80	1400
1980/81	2501
1981/82	2980
1982/83	4206
1983/84	5703
1984/85	7200

(Government of India projection)

The breeder seed production units are located at 34 centers (agricultural universities and ICAR institutes), and 14 agricultural universities conduct seed technology research. The NSP has provided the financial assistance to create infrastructure and seed storage facilities for breeder seed production, and to create facilities and train scientists for conducting seed technology research. These activities are supervised by a coordinator based at the Indian Agricultural Research Institute, New Delhi.

The scheme helps to supply and maintain a constant flow of breeder seed to the NSC, the state seed industry, so that adequate quantity and quality of foundation and certified seed are supplied. The NSC is also helping to organize sound seed technology research in the country to produce good quality seed and to make the seed industry self-reliant.

Four annual workshops on seed technology research have been organized under the NSP, with the fifth to take place in August-September 1984. At workshops, results obtained at various centers are presented and discussed, and future experiments planned. After careful analysis of results obtained from seed technology research units, existing field and seed standards may be revised.

To meet the increased responsibility for certified seed production, a number of state seed corporations were developed. These corporations are 35% owned by the state governments or their agencies, 35% by growers, and 30% by the central government through the NSC. Within each state, compact areas of high productivity have been selected for

development. The project has provided funds to bring the compact areas to a state of high productivity, with long-term funds for development and short-term funds for current inputs.

Training of Personnel and Seed Research

In the early 1960s, the need for trained manpower in seed programs was realized. Since then, several training courses in seed production and technology have been conducted by the Indian Agricultural Research Institute, the NSC, the G.B. Pant University of Agriculture and Technology, and other institutions. An elective undergraduate program in seed technology is offered by the University of Pantnagar, and post-graduate programs in seed technology are offered by the Tamil Nadu Agricultural University, Coimbatore; the University of Agricultural Sciences, Bangalore; and the Indian Agricultural Research Institute, New Delhi. Several agricultural universities also offer extension education in seed technology.

Seed research is carried out both at ICAR institutes and at agricultural universities. Twenty-four research institutes and 21 agricultural universities are engaged in seed research. Most of these institutions carry out research on isolation distances, planting ratio, seed storage, germination, dormancy, vigor, seed maturity, various aspects of seed pathology, processing, drying, quality control, control of insect pests, marketing, and seed extension.

Seed Industry in the Private Sector

The private seed industry has an important role to play in the overall seed industry development in India. Over the last 10 years, the seed industry has enlarged considerably, with an estimated 2,000 small, medium, and large seed dealers in business, of which about 200 appear to have a permanent stake in the seed business in India. The Indian Society of Seed Technology published a directory of seed personnel in India in February, 1980. A similar directory has been published by the All-India Seed Growers' Merchants and Nurserymen Association. The private seed industries are playing an important role both in disseminating certified seeds in India and in exporting seeds to different countries. Custom seed production has been taken up by various Indian seed companies, including the NSC.

The Seed Industry in Kenya

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Introduction

Kenya has a basically agricultural economy. Only 20% of its land is arable, 20% is grassland, and the rest is mainly dry bushland. The population, estimated at 17.5 million in 1983, is increasing at 4.1% per annum. It is estimated that by the year 2000, there will be only 0.5 ha of potentially productive land per person. Agricultural production has doubled over the past two decades, mainly through the expansion of area under cultivation, but also through the introduction of hybrid maize. Much of the expanded area is farmed by small-holders. The government is dedicated to increasing food production through good seed production programs.

Plant Breeding

Breeding and research are carried out almost exclusively by the public sector in several national research stations, each dealing with one or several crops. The National Plant Breeding Station at Njoro is responsible for wheat, barley, and oil crops (sunflower, rapeseed). The Kenya Breweries and the East African Industries, two private organizations, cooperate in breeding and research on barley and oil crops, respectively.

The National Agricultural Research Station at Kitale has the mandate for maize, pasture, and forage breeding and research. The Kenya Seed Company carries out breeding activities in maize and a number of other crops such as sunflower and rapeseed. The National Potato Research Station breeds potatoes, and other research stations work on cotton, dryland crops, and vegetables. Research stations are often assisted by international research centers.

These breeding activities have produced improved varieties of Kenya's main agricultural crops. The area planted with certified seed of improved varieties is summarized in Table 1.

Table 1. Area under certified seed of improved varieties in Kenya.*

Crop	Area planted with certified seed (ha)	Area planted with certified seed as % of total area planted
Maize	518,000	43
Wheat	56,000	54
Barley	24,000	100
Potato	660	1

*Source: National Seed Quality Control Service Evaluation Report 1983, Ministry of Agriculture, International Agricultural Centre, Wageningen, The Netherlands.

Variety Testing and Release

According to the Seeds and Plant Varieties Act, new varieties can only be released if they show superior agricultural performance and are sufficiently distinct, uniform, and stable (DUS). To establish the agro-ecological value of new varieties, a system of national performance trials has been set up. Such trials in the different ecological zones of the country are carried out by the plant breeding stations and monitored by the Quality Control Agency. According to the Seed Act, such experiments have to be conducted over three subsequent years. DUS tests are carried out simultaneously.

After three years of testing, Specialist Variety Release Committees may propose the release of new varieties to the National Release Committee.

Seed Production

In 1956, a group of farmers founded the Kenya Seed Company (KSC) to meet the demand for seed. Owned at just over 50% by the Kenya government, it is the major company for producing agricultural seeds, maize, wheat, grasses, and sunflower. The KSC obtains breeder seed from breeding stations, while multiplication to basic seed is carried out at the seed company's farm.

Certified seed is produced by seed growers on contract with the company; growers receive a premium of 20 to 25% above the commercial grain price, which is relatively high to encourage the farmer to grow seed. Seed growers can use the KSC's management service for land preparation, sowing, and other operations. The company's field staff closely follows the various multiplication steps.

Production of potato seed is carried out by the Agricultural Development Corporation, while vegetable seeds and beans are produced and/or imported by a large number of small seed companies.

Processing

The KSC has modern processing plants and storage facilities in two different locations. There is also a special plant to dry and process maize which is harvested at physiological maturity, when nutrients are no longer being taken up and the seed need not be left on the plant. Such early harvesting reduces harvest losses to insects, disease, and rodents, and also allows much more time for drying and processing. The seed company has a separate basic seed processing plant on its farm.

Marketing and Distribution

Certified seed of most agricultural crops is marketed through a distribution network of 30 Kenya Farmer Association (KFA) outlets and 4000 retailers (often simple village groceries). The KFA also markets all other farm inputs. The network ensures that seed and related farm

inputs are always accessible to the farmer. Seed for small farmers is packed in small quantities (1, 5, and 10 kgs) and sold mainly through the village grocery outlets.

Concerning price, certified seed of wheat, for example, costs twice as much as commercial grain. For hybrid maize, the difference in price between commercial grain and certified seed is much greater.

It is important that the farm produce can be sold easily. The National Cereals and Produce Board, a para-statal organization responsible for the purchase of cereals, buys 5% of the national maize crop and all of the wheat crop. Prices, particularly those of essential food crops, must be approved by the ministerial pricing committee.

Quality Control

Kenya's entire seed program is monitored by the National Seed Quality Control Service (NSQCS), which is considered one of the best regulatory services in Africa south of the Sahara. The NSQCS certifies major agricultural crops (maize, wheat, barley, oats, triticale, potatoes, rapeseed, sunflower, and grasses) through seed testing, field inspection, and sampling of processed seeds; grows post-control plots; and certifies some horticultural crops. The service also controls imports of seeds through sampling, testing, and nursery plots; carries out varietal description (DUS testing); registers seed growers, merchants, and others; and monitors variety performance testing in different ecological zones.

Kenya, a full member of the International Seed Testing Association, issues orange and yellow certificates. Kenya is also a member of the Organization for Economic Cooperation and Development (OECD) and certification is carried out according to OECD certification schemes.

In 1976, a variety section was established to officially coordinate variety testing and, eventually, to implement Plant Breeder's Rights. Although these rights have not been implemented, Kenya is an observer in the International Union for the Protection of New Varieties of Plants (UPOV), which works toward uniformity in granting Plant Breeder's Rights.

Legislation

The seed industry is regulated by the Seeds and Plant Varieties Act and its regulations. Although the Seed Act was enacted many years ago,

its regulations have still not been approved by the Minister of Agriculture, mainly because the regulations for Plant Breeder's Rights were not accepted by many government officials.

Extension and Infrastructure Credit

An efficient extension service, coupled with vigorous promotion and extension by seed companies (primarily the Kenya Seed Company), have contributed to the rapid dissemination of improved varieties. Radio broadcasts, leaflets, and field days sponsored by breeding stations and the Quality Control Agency have all increased food production through the use of quality seed. An adequate agricultural infrastructure has been of considerable assistance in providing seed to the farming community. The Agricultural Finance Corporation advances seasonal credit to farmers for maize, wheat, and potato growing. Loans are given only if certified seed is used.

The Development of the Seed Multiplication Program in Syria

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Introduction

In all countries and climates of the world, harvest quantity and quality are determined not only by soil fertility, fertilization, cultural practices, and appropriate chemical application, but also by carefully chosen varieties and by the use of disease-free seeds with good germination capacity.

Multiplying selected seeds is the only way to pass on to farmers the results of agricultural research. Crop production can thus be increased through selecting varieties that perform better than traditional ones, as well as providing high quality seeds to farmers.

Organization of Syria's Seed Multiplication Program

Syria has a sound certified cereal seed industry with all the components to meet substantial needs for wheat and barley seeds. Four organizations play a role in the country's seed industry:

1. *Research Directorate of the Ministry of Agriculture*: plant breeding and selection, release of new varieties, and production of breeder seed for the General Organization for Seed Multiplication.

2. *General Organization for Seed Multiplication (GOSM)*: seed multiplication, quality control, and storage, with some marketing; established in 1975. The GOSM aims to increase production of all crops: cotton, wheat, barley, maize, and potato.

3. *General Organization for Silos and Seed Plants*: seed processing in cooperation with the GOSM.

4. *Agriculture Cooperative Bank*: credit and some marketing.

Syria's program emphasizes training staff for the different sectors of the program, including managers, workers, and growers. Production is another important aspect; this is done by contract with the producer (the farmer/seed grower, cooperative, or government farm) in the multiplication areas designated each year by the GOSM. (See Table 1 for seed production of various crops in Syria.)

Table 1. Seed production in Syria in tonnes (1000 kg), 1976-83.

	1976	1977	1978	1979	1980	1981	1982	1983
Cotton	22491	23412	23159	24350	23983	23576	24970	27900
Wheat	1485	3846	22379	51746	24153	23580	38250	53238
Potato	2018	4736	6801	6014	8548	9903	10020	12372
Maize	243	213	143	180	175	128	114	101
Barley	-	-	-	-	55	739	1078	1260
Faba beans	-	-	-	-	14	17	26	78

The National Institute for Agricultural Research in Syria supplied nucleus seed of a number of varieties of various crops in 1983, as shown in Table 2. Other research centers such as ICARDA and the Arab Center for Studies of the Arid Zones and Dry Lands (ACSAD) have recently submitted nucleus seed of wheat (including varieties Sham 1 and Sham 2) and barley to the GOSM.

Syria has adopted the following terminology for the stages of cereal multiplication: nucleus, foundation, registered, certified, and improved seed.

Several inspections are made by the GOSM's regional staff and the Ministry of Agriculture's inspection service. Representatives of the National Institute for Agricultural Research also help to inspect foundation seed fields. (See Table 3 for field inspection standards.)

Before the harvest is bought, the seed testing laboratory carries out supplementary tests for varietal purity, analytical purity, germination, and seed health.

Table 2. Nucleus seed supplied by the National Institute for Agricultural Research in Syria, 1983.

Crop	Variety
Cotton	Alep 40, Alep 33, Tashkend.
Durum wheat	Jazira 17, Jouri 69, Bohouth 1, Sham 1, Haurani Sinator Capelli.
Bread wheat	Mexipak, Siete Cerros, Florence Aurore, Sham 2.
Barley	Arab White, Arab Black, Badia.
Maize	Ghouta 82, Synthetic 551.
Potato	Arran Banner, Aran Consul, Sponta, Draga, Radoza, Nicola, Tarban Volcano, Lotina, Ilona.

Table 3. Standards for field inspection (maximum allowable plants or heads at final inspection).

Description	Seed generation			
	Nucleus	Foundation	Registered	Certified
Off-types (plant or ear)	1:9000	2:6000	4:6000	6:6000
Other crops that are difficult to remove by cleaning	1:9000	2:6000	4:6000	6:6000
Other harmful plants (weeds, oats, etc)	0	1:6000	1:6000	2:6000
Plants affected by seed-borne diseases	3:9000	3:6000	6:6000	6:6000

Seeds are then processed, a step that is extremely important for seed quality and requires great care, especially when there is more than one variety in a processing plant.

Processing takes place at 11 centers located in the various multiplication areas and belonging to the General Organization for Silos and Seed Plants. The capacity of each plant is 10,000 tonnes/season. The treated seeds are put into polyethylene bags of 50 kg capacity and labelled with the following information:

1. Type of seed and variety.
2. Multiplication class.
3. Name of the person responsible at harvest.
4. Original farm identification number and village.
5. Date of bagging.
6. Seed treatment.
7. Syrian Arab Republic, Ministry of Agriculture, GOSM.
8. Name of seed processing plant.

Growing a crop for seed is more expensive than growing a crop for grain, and the GOSM encourages the seed grower by reimbursing him with the cost of transport from the production area to the processing plant. In addition, the GOSM gives a bonus of 20-25% above the grain price.

In order to encourage the use of certified seed, the High Council of Agriculture fixes the sales price at a lower level than the actual costs. (For example, the 1983 sales price was set at 70% of actual costs.)

In Syria, seed is distributed either through the 53 branches of the Agricultural Bank or through the eight branch offices of the GOSM. The branch offices of the Agricultural Bank serve as agencies for both ordering and delivery. For this service, the bank receives a 2% commission from the GOSM on the sales price. In 1983, 14,948 tonnes were distributed.

Seed Anatomy, Development and Composition*

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Introduction

Seeds have always been the great staple food of the world, feeding more people than any other type of food. The endosperm and cotyledons of seeds, with their rich food reserves for the developing embryo and seedling, are highly nutritious and easily stored. Of particular importance are the carbohydrate-rich cereals and the protein-rich legumes used directly for human consumption. Other seeds provide fiber, spices, beverages, oils, drugs, and plants for flowers and other aesthetic purposes.

The seed is a unique organism, often providing its own method of dispersal. Most importantly, the seed contains an embryonic plant, a link between generations, with capacity for growth under specific conditions.

An understanding of seed makeup and behavior is essential for agricultural research.

Seed Formation

Figs. 1-4 illustrate flower and seed structure and development. The seeds of angiosperms originate from the meristematic tissue of the ovary wall. One tissue cell divides twice to ultimately form four

*Adapted from "Introduction to Seed Science and Technology," Technical Manual No. 10, ICARDA, Aleppo, Syria.

haploid (1n) megaspore cells. Normally, only one megaspore is functional, while the other three degenerate.

The megaspore cell enlarges to become the embryo sac and the nucleus divides three times to give eight haploid nuclei (1n). Cell walls form between the nuclei, resulting in three antipodal cells at one end, two polar nuclei (without cell walls) near the center, and the egg apparatus at the other end. The two polar nuclei fuse to give a diploid nucleus (2n).

The ovule or ovules around the embryo sac develop by the growth of collars or integuments which ultimately fuse to become the testa (seed coat) of the mature ovule. The developing ovule is attached to the placenta of the ovary by the funiculus which forms the hilum when the seed detaches at maturity. The point where the integuments meet is the micropyle, and the region of integumental origin and attachment, usually opposite the micropyle, is the chalaza.

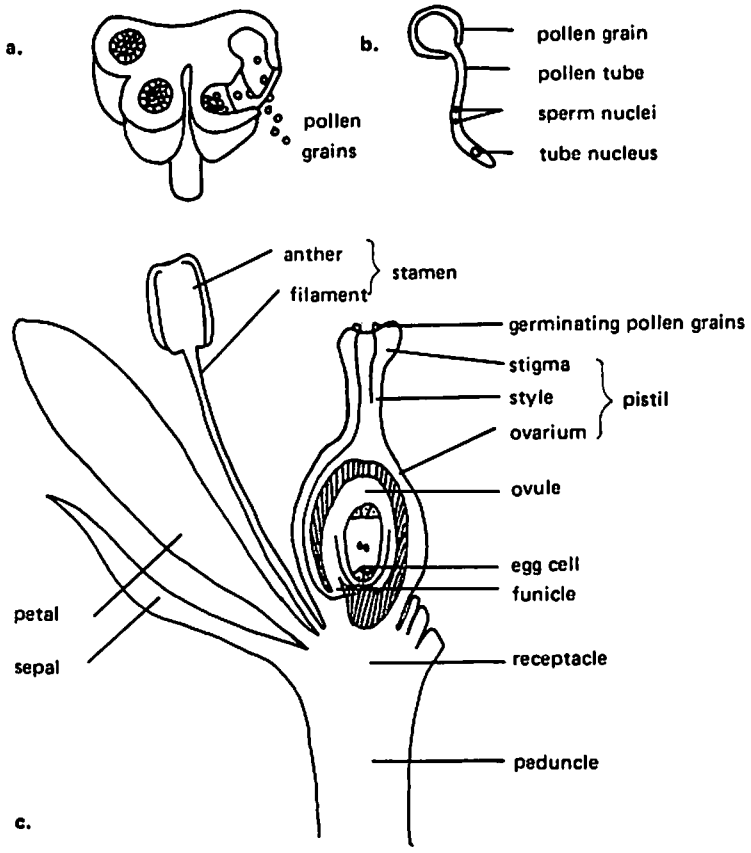

Fig. 1. Structure of a dicot flower. a. detail of anther (cross section); b. germinating pollen grain; c. length section of a dicotyledonous flower, with a one-ovuled ovarium (schematic).

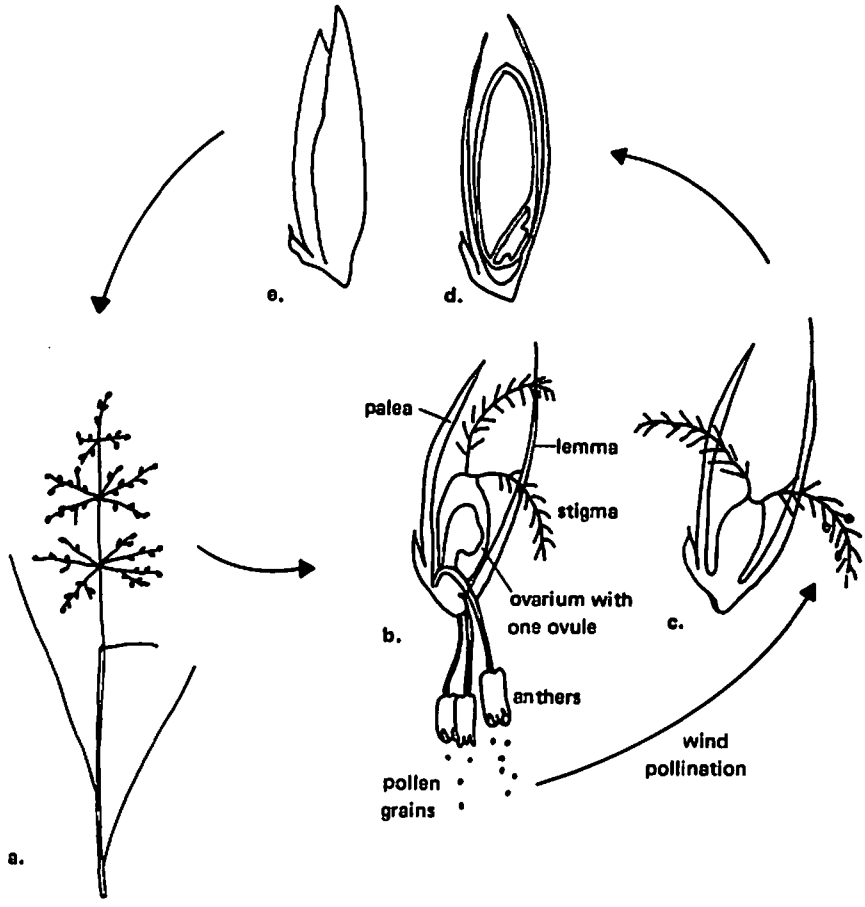

Fig. 2. Life cycle of a grass. a. flowering plant; b. floret (grass flower) in length section, showing the ovarium with one ovule and two feathery stigmas, and the three anthers; c. floret with pollen grains caught in a stigma; d. length section of a floret with mature caryopsis; e. outside view of floret or "grass seed."

During the period of flower development, haploid (1N) pollen microspores are produced in the microsporangia of the anther. At maturity the microspores are released to begin fertilization of the developed ovule.

When pollen lands on the stigma of the ovary, it germinates, sending the pollen tube down the style through the micropyle into the embryo sac and double fertilization occurs.

The ovary wall or pericarp of angiosperm fruits is composed of three more or less distinct layers: the exocarp (outer layer), the mesocarp (middle layer), and the endocarp (inner layer). The relative development of each in various species often determines fruit structure and morphology.

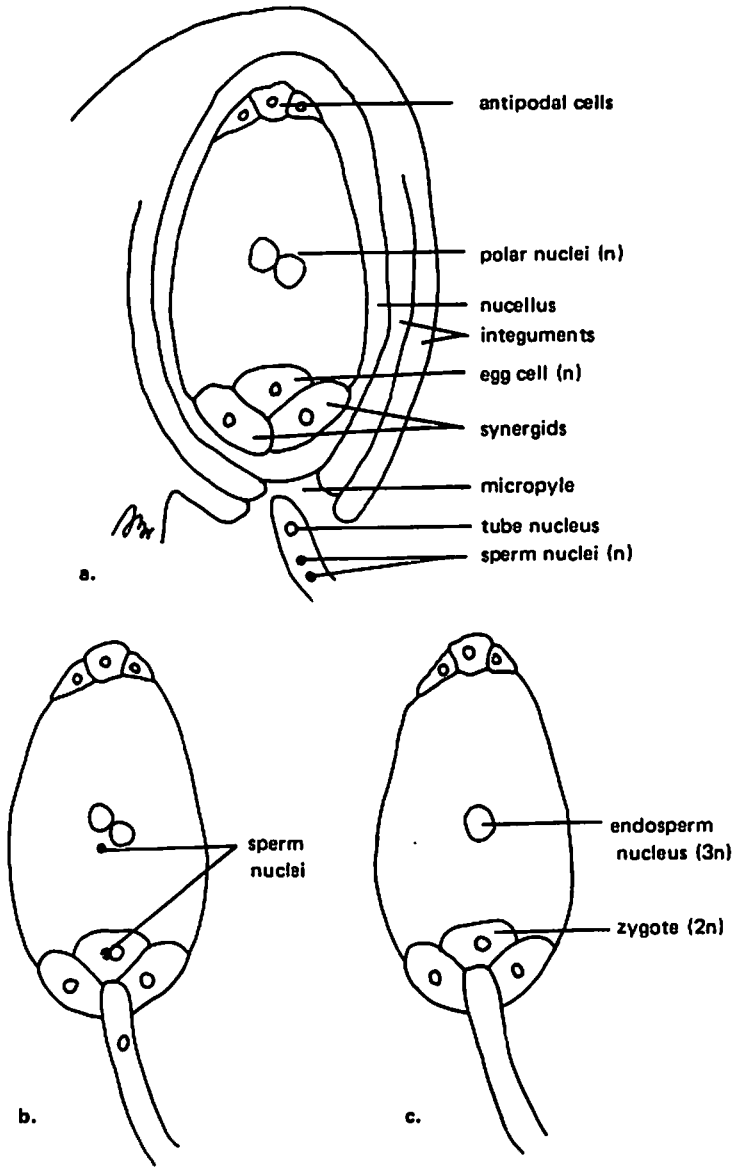

Fig. 3. The process of double fertilization. Both the egg cell and the polar nuclei are fertilized.

A true seed is a fertilized mature ovule that possesses an embryonic plant, stored food material, and a protective coat or coats.

The embryo is made up of one or more cotyledons, a plumule (embryonic bud), hypocotyl (stem portion), and radicle (rudimentary root).

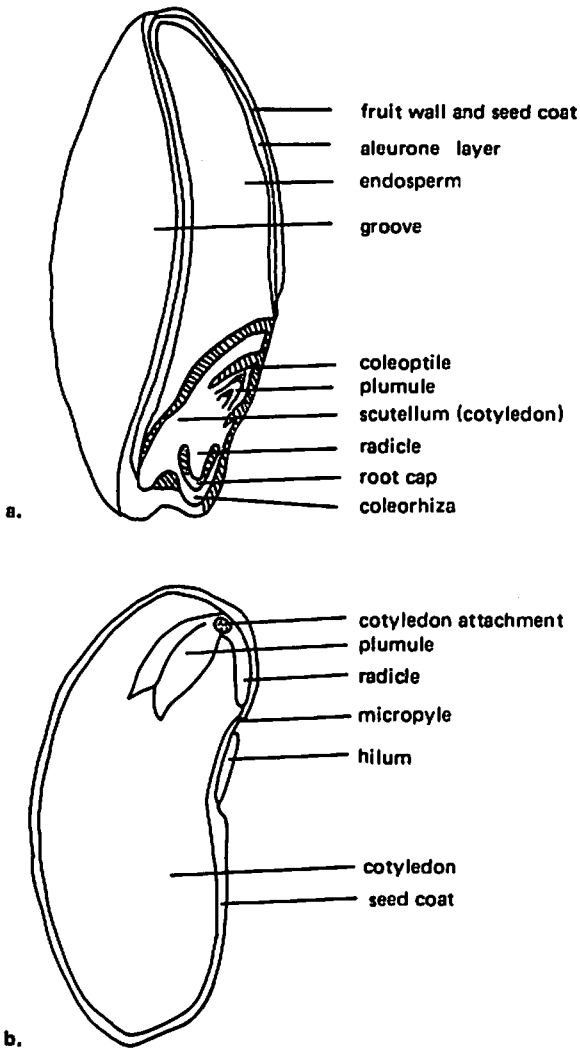

Fig. 4. A monocot and a dicot dispersal unit. a. caryopsis of wheat (*Triticum aestivum*); b. seed of common bean (*Phaseolus vulgaris*).

The wheat grain is a caryopsis in which the single cotyledon is modified to form the scutellum, which absorbs food from the endosperm.

The bean seed, one of several in the legume fruit, represents a complex of seed types found in the family Leguminosae. External structural features which are found in most of the species of the family include:

The hilum: the remainder of the attachment point of the seed in the pod. It may vary in color, size, and position on the seed.

The micropyle: a minute pore at the radicle end of the hilum, apparently with no diagnostic value.

The strophiole: a point of weakness in the seed coat at the other end of the hilum associated with breakdown of impermeability in some pasture legumes, such as subterranean clover.

The raphe: evident in certain species as a raised ridge between the strophiole and chalaza, with no known function.

The chalaza: evident as a small dark-colored area on the surface of many legume seeds near the upper end of the cotyledons. It may be an important diagnostic feature, as in the vetches.

The myriad external variations in seed size, shape, color, and surface may be important functional and diagnostic differences. Seed weight may vary from almost 10 kg, for a double coconut seed, to 0.08 mg for a tobacco seed. Common seed shapes are ellipsoid, globose, lenticular, oblong, ovoid, reniform, and sectoroid. Seed surfaces vary from highly polished to greatly roughened, with attached appendages including wings, spines, and hairs. Seed color may vary from black, red, green, and yellow to white, although brown and black are most common.

Seed Development

The zygote begins division to ultimately form the seed embryo. Although the mature embryos of monocots (grasses) and dicots (legumes) appear to be considerably different, their patterns of development are similar. The endosperm and other tissues, however, develop quite differently, leading to structural differences in the mature seed.

The endosperm of monocots usually reaches maximum development at physiological maturity and persists to comprise the major part of the seed. In dicots, the endosperm may not develop or may be used up by the developing embryo and may not be part (or only a small part) of the mature seed.

The outermost layers of the endosperm are known as the aleurone layer. This layer functions both as storage tissue for protein granules and for secretion of hydrolytic enzymes, which when activated during germination help to break down storage tissues.

Seed Growth

After sexual fusion, the developing seed begins to increase its weight by soaking up nutrients and water associated with rapidly accelerating cell division and elongation.

The changes can best be illustrated by the growth of wheat and pea seeds which represent monocot and dicot seeds. Maximum dry weight is achieved at about 40 days after flowering. Initially, amounts of sucrose and reducing sugars are high in both the endosperm and testa-pericarp, but they decline markedly as they are converted to starch. In terms of nitrogenous substances, there is a steady increase with time in protein accumulation in the endosperm, but little increase in the testa-pericarp. The general metabolic activity of the grain is mirrored in the dramatic decreases with time of RNA and DNA in the endosperm, compared with the testa-pericarp.

Seed Chemistry

A knowledge of the chemical composition of seeds is essential because seeds are a basic food source for both man and animals. They are also an important source of chemicals for industry, medicines, drugs, and various antimetabolites which affect human and animal health and nutrition. Seeds, furthermore, contain reserve food supplies and growth substances that influence seed germination and seedling vigor as well as seed storage and longevity.

Most knowledge of the chemical composition of seeds covers the cultivated species which supply food and industrial raw materials. Information on the seeds of wild species is relatively scanty.

The primary chemical constituents of seeds are water, protein, lipids, fiber, and carbohydrates. The general chemical composition of a range of seeds is shown in Table 1. Agriculturally important seeds may be divided into three groups: carbohydrate-rich seeds, which are all grasses; protein-rich seeds of legumes; and oil-rich seeds. Some seeds, however, such as those of soybean and peanut, have relatively large amounts of both protein and lipid.

In addition to these main groups, many other chemical substances are found in mature seeds in smaller amounts, such as a wide range of metabolic enzymes, tannins, alkaloids, growth regulators, and vitamins. All of these compounds are important in determining the ultimate use of a particular seed species.

Table 1. General chemical composition of seed (% by weight).

Species	Water content	Protein	Fat	Fiber	Carbo-hydrate	Minerals
Carbohydrate-rich						
Corn (Dent No. 1)	13.0	8.9	4.0	2.0	70.8	1.3
Japanese millet	10.2	10.6	4.9	14.6	54.7	5.0
Oats	9.8	12.0	4.6	11.0	58.6	4.0
Rice (brown)	12.2	9.1	2.0	1.1	74.5	1.1
Rye	10.5	12.6	1.7	2.4	70.9	1.9
Sorghum (grain)	10.4	10.8	2.8	2.3	71.7	2.0
Wheat (average, all types)	10.5	13.2	1.9	2.6	69.9	1.9
Protein-rich						
Alfalfa	11.7	33.2	10.6	8.1	32.0	4.4
Beans (faba type)	10.0	22.9	1.4	4.2	57.3	4.2
Clover (red)	12.5	32.6	7.8	9.2	31.2	6.7
Cowpea	11.0	23.4	1.3	3.9	56.8	3.6
Lupin (sweet, yellow)	11.1	39.8	4.9	14.0	25.7	4.5
Pea (field)	9.3	23.4	1.2	6.1	57.0	3.0
Soybean	10.1	37.9	18.0	5.0	24.5	4.6
Vetch	9.3	29.6	0.8	5.7	51.5	3.1
Oil-rich						
Cotton seed	7.3	23.1	22.9	16.9	26.3	3.5
Linseed	6.2	24.0	35.9	6.3	24.0	3.6
Mustard (yellow)	4.1	23.0	38.8	5.0	23.6	5.5
Peanut	5.4	30.4	47.7	2.5	11.7	2.3
Rape	9.5	20.4	43.6	6.6	15.7	4.2
Safflower	6.9	16.3	29.8	26.6	17.5	2.9
Sesame	8.0	22.3	42.9	10.3	10.9	5.6
Sunflower	6.4	16.8	25.9	29.0	18.8	3.1

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Suitable Areas for Seed Production

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Seed should be multiplied in the most favorable climatic regions to obtain full expression of cultivar characters, maximum possible yield, and good harvest conditions. Commercial seed should be produced in relatively dry and cool locations.

Light intensity and duration as well as temperature are the main factors that affect a crop plant's switch from vegetative to reproductive phase. When a plant switches to the second phase, vegetative growth lessens and may even stop. This is an important physiological consideration for seed production; if a variety which requires a long photoperiod is planted in an area with a short daylength, the plant may not head at all.

The following factors should be considered when choosing a suitable area for seed production.

Light

Plants have been divided into short-day plants (SDP), long-day plants (LDP), and day-neutral plants. If SDP and LDP plants are not grown under the correct daylength, they remain vegetative and do not flower. Plants grown in temperate regions tend to flower during long days, while those grown in tropical regions require a shorter day. Requirements for daylength are generally characteristic of a species; within species, however, cultivars adapted to different daylengths have been developed. Wheat cultivation has spread throughout the world because cultivars adapted to different daylengths have been developed.

Light intensity also influences seed production through photosynthesis; for example, the flag leaf and ear of wheat perform all photosynthesis responsible for grain yield. Light intensity also affects pollination as well as drying and ripening of seed.

Temperature

The changeover from vegetative to reproductive phase is also influenced by temperature, which affects seed germination and crop growth and development. In the USA during cotton seed germination, for example, soil temperature falls considerably lower, thus giving lower emergence. This is the basis of the cool germination test for cotton. In wheat, certain varieties with a chilling requirement are sown in early winter to satisfy this requirement at an early stage of growth, while appearance of ears requires relatively warmer temperatures. If such cultivars are sown after the cold weather has passed, the plants remain vegetative and no ears form. Cultivars are also available, however, which do not require chilling temperatures and can be sown on warm spring days.

Temperature influences many other biological processes. Pollination, seed setting, and ripening are all favored by warm weather at the appropriate time. For example, 18-19°C for four to five weeks has been found to be most suitable for maturity of the wheat seed crop. Excessive temperatures, however, may inhibit the development of ovules and fruits and cause shedding of flower buds or young fruits, as is the case in pulses.

Rainfall

Rainfall is important for crop growth, affecting water supply and humidity. Flowering, pollination, and seed setting require moderate humidity, while seed maturation requires low humidity. High humidity encourages the production of diseased seeds, while dry climates favor the production of healthy seeds.

Excessive rainfall leads to a higher incidence of diseases, makes seed harvesting extremely difficult, and interferes with pollination. It can also delay maturity, and cause pre-germination of seed and shattering.

Wind

Strong winds are unfavorable for seed production. They can damage the seed crop through lodging, shattering, and shedding of seeds. Wind direction influences crop pollination.

Soil and Plot Characteristics

Soil should be well-drained, fertile, and neither acidic nor alkaline. In areas where disease spreads through both seed and soil, soil must be free from pathogens. Fusarium wilt on many food legumes (e.g., *Cicer*) establishes itself in the soil through seeds and thus spreads further from the soil.

Soil should also have an adequate supply of mineral nutrients, some of which influence seed quality. Soils are usually deficiént in trace elements that may be important to a crop; a deficiency in soil boron, for example, causes "hollow heart" defect in pea seed. Areas without mineral deficiencies should be selected for seed production.

The soil must also be free from weed seeds. It is much easier to produce seeds on such soils than to control weeds later.

Seed plots should be selected with several considerations in mind. The plot's soil texture and fertility should fit the seed crop's requirement. The plot should be free from volunteer plants, weeds and weed seeds, other crops, soil-borne diseases, and insect pests. Adequate isolation distance must be available, and the seed plot must be levelled.

Seed Certification

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Introduction

Seed production has constraints that differ from those of crop production. A successful seed program is able to supply a sufficient quantity of high quality seed at the required time, at reasonable cost, and at the place it is needed. Good seed companies have systems of quality evaluation to ensure that the seed they sell is of good quality. Such seed has high germination and vigor; is reasonably pure, both genetically and physically; and is free from seed-borne diseases and insect damage.

Good seed can be produced by controlling seed production. The processes of seed multiplication and processing must avoid or minimize the risk of mechanical or genetic contamination. In addition, minimum field and seed standards must be set, and each seed lot must be checked against these standards at the appropriate time.

To ensure this control, seed certification is necessary--a process that secures, maintains, and furnishes high quality seed and propagating materials of superior crop varieties that are grown and distributed to ensure desirable standards of genetic identity, physical purity, and other quality attributes. Certification has five phases:

1. Verification of land requirements.
2. Verification of seed source.
3. Inspection of the seed crop in the field.
4. Inspection and testing of each seed lot and seed sample during processing and bagging.
5. Tagging and labelling to identify the seed, and sealing.

Inspections

Field inspections are made of the standing seed crops, while later inspections and tests are done in the laboratory on representative seed samples collected from seed lots. These lots come from the seed crops that were inspected and approved at the field stage for conformity to prescribed standards.

The primary objective of field inspections is to confirm that seed produced from a crop grown for seed purposes, is of the designated variety, and that it has not been contaminated genetically and/or physically beyond certain specified limits.

The objective of field inspection is fulfilled by verifying that the seed crop is:

1. Grown in a field that satisfies the prescribed land requirements.
2. Raised from seed whose source is approved.
3. Provided with the prescribed isolation and/or with the prescribed number of border rows in hybrid seed production.
4. Planted in the prescribed ratios of female (seed) and male (pollinator) parents, in the case of hybrid seed.
5. Properly rogued to remove contaminating factors such as plants/ears, objectionable weeds, and other crop plants, in conformation with the standards for these factors.
6. True to the characteristics descriptive of the variety.
7. Harvested properly to avoid mechanical admixture.
8. Grown in compliance with other special requirements for the crop concerned.

Field observations are then compared with a set of certification norms which are specific for each crop. The seed certification standards specify the requirements for seed crops in relation to previous crops, isolation, varietal purity, other crop plants, objectionable weeds, and freedom from certain designated diseases. They also specify the required physical quality standards for seed lots including pure seed, inert matter, other crop seed, weed seed, and objectionable weed seed, as well as standards for germination and moisture.

The authority of an agency to inspect a seed crop depends basically on whether .the inspection is for certification, or only to assure the production of high quality uncertified seed. For official certification, only the officially notified agency for the region concerned has the authority to perform the inspection. If the inspection is only to ensure the high quality of uncertified seed, any

qualified agency such as the seed production or contracting agency may make the inspection.

Eligibility of crop varieties for certification inspection

In addition to being of a kind and variety notified for the region concerned, a foundation seed crop must have been grown from breeder seed from an approved source recognized by the certification agency, or from foundation seed that can be clearly traced to breeder seed. A certified seed crop must have been grown from foundation seed from an approved source recognized by the certification agency, or, if approved by the certification agency, from certified seed, provided the genetic identity and purity will not be significantly altered. These classes must conform to the following descriptions:

Breeder seed: The seed or vegetative propagating material directly controlled by the originating or sponsoring plant breeder of the breeding program or institution. The production of breeder seed is personally supervised by a qualified plant breeder. This seed provides the source for the initial and recurring increase of foundation seed.

Foundation seed: The progeny of breeder seed or foundation seed which can be clearly traced to breeder seed. Production, supervised and approved by the certification agency, should be handled so as to maintain specific genetic identity and purity and conform to certification standards specified for the crop.

Certified seed: The progeny of foundation seed. Its production should be handled to maintain specific genetic identity and purity according to standards specified for the crop being certified.

Certified seed may be the progeny of certified seed, provided this reproduction does not exceed two generations beyond foundation seed, and further provided that the certification agency determines that genetic identity and purity will not be significantly altered. However, in the case of highly self-pollinated crops, certification of one further generation may be permitted. Certified seed produced from certified seed shall not be eligible for further seed increase under certification, except in the case of highly self-pollinated crops, for which certification of one further generation may be permitted. Certification tags for certified seed not eligible for further increase shall be labelled "not eligible for further seed increase under certification." However, this condition may be lifted as long as the genetic identity and purity are maintained.

Inspection timing

Verification of all factors affecting seed quality in the field may not normally be possible or necessary in a single inspection, since all factors may not be apparent or may not occur at the same time, or all of them may not affect seed quality at a particular growth stage. Hence, more than one inspection--phased to cover all the important stages of crop growth--is required in most crops. The number of inspections and the stages of crop growth at which they should be conducted vary from crop to crop, depending on the crop's duration, nature of pollination, susceptibility to contamination, disease-susceptible stage(s), nature of the contaminating factor(s), and other variables.

For convenience, the stage of crop growth at which inspections are generally made in sexually-propagated species are classified as follows:

Pre-flowering stage: The entire period preceding flowering is the pre-flowering stage. However, for inspections, this includes the seedling, vegetative, and flower bud initiation stages, and all such growth phases prior to emergence of the panicle or inflorescence. In Graminaeceous crops, this stage extends up to the time of emergence of the flag leaf.

Flowering stage: In this phase, the flowers or spikelets of the inflorescence or panicle have opened, the stigma is receptive, and the anther is shedding pollen.

Post-flowering stage: In this stage, the receptivity of the stigma and the pollen-shedding of the anthers have ended, and the fertilized ovule starts to develop into a seed. This includes both the milk stage, when the contents of the fertilized ovule are in the form of a white milky fluid, and the dough stage, when the seed contents are being transformed into a more solid, pasty substance that yields to pressure.

Pre-harvest stage: In this phase, the seed becomes harder and approaches or reaches physiological maturity. The seed is fully formed, but is high in moisture content.

Harvest stage: In this phase, the seed is physiologically mature and is sufficiently dry to permit safe and easy harvesting and threshing, or is physiologically mature and can be dried for relatively safe storage.

In vegetatively or sexually-propagated crops such as potato, classifications such as pre-flowering, flowering, and post-flowering may not be appropriate. Instead, other classifications are used: sprouting, seedling, tuberization, tuber-hardening, and haulm-cutting/de-haulming stages. In root and bulb crops, the enlarged root/bulb formation stage precedes pre-flowering; lifting and replanting are done after complete root formation. In these crops, inspection at lifting and replanting is essential.

In cross-pollinated crops, inspections during flowering are essential to verify freedom from genetic contamination; in self-pollinated crops, inspections during flowering are helpful in distinguishing off-types by plant characters.

Observations during inspections

Factors to be observed during field inspections vary among crops and growth stages. In general, the source of genetic and physical contamination must be observed and the degree of occurence estimated. Genetic contamination is common in cross-pollinated crop species.

Sources of physical contamination include seed from other varieties of the same species or other crop plants, weed plants, and plants/heads with seed carrying disease-causing pathogens. Seed of other varieties/kinds may occur physically mixed with the crop seed without altering the genotype of the crop seed. This type of contamination is common in both self- and cross-pollinated crops. While genetic repurification is tedious and takes several generations, physical repurification is often easier, since it may be possible to separate and remove the contaminating seed mechanically.

Sources of contamination can be broadly classified into one of the following categories (for self-pollinated crops).

Off-type: This is a plant of the same species as the seed crop but deviating in the expression of morphological characteristics. To designate a plant as an off-type, it is not necessary to identify it definitively as another variety. Plants of other varieties, however, are also called off-types.

Inseparable other crop plants: These cultivated crop plants, found in the seed field, have seed so similar to the crop seed that it is difficult to separate them mechanically in an economical way.

Objectionable weed plants: These are plants of weed species that are harmful to the seed plant being grown.

Diseases: Plant diseases, caused by fungi, bacteria, viruses, or nematodes; may become pronounced under nutritional deficiencies. Seed is known to be partly or wholly responsible for transmitting the disease-causing pathogens of some diseases from one generation to the next. Seed may carry the pathogen either internally (internally seed-borne) or externally (externally seed-borne) or in both ways. Although economical and effective measures for prevention and/or control of seed-borne infection are available for some such diseases, practical and effective measures are not available to prevent seed transmission of some disease-causing pathogens. In such cases, an effective method to prevent seed transmission of the pathogen is to ensure that possibly infected seed is not mixed with clean seed, by eliminating from seed fields all plants whose seed is suspected to carry pathogens.

Taking field counts

Examining all plants in a field is obviously impossible, so a random count should be taken. The number and method of counts vary from crop to crop. For all crops, five counts may be taken on an area up to five acres (about 2.03 hectares), and an additional count for each five additional acres.

Procedure:

The procedure for taking counts in thickly-sown row crops such as wheat, soybeans, or paddy is as follows:

1. Enter the seed field from any side at a randomly-selected site and determine the average number of heads/plants/step. This process should be repeated at five random locations, and the average number of heads/step calculated.
2. Determine the number of steps required to include sufficient plants/heads (e.g., 1000 earheads for wheat and barley or 500 plants for chickpea).
3. Walk through the field according to one of the different schemes shown in Fig. 1 so that all portions of the field are represented in the counts.
4. Randomly select any row, and from any point in that row take enough consecutive steps to include a sufficient number of plants or earheads (e.g., 1000 earheads for wheat), or take 10 consecutive steps in that row.
5. Within these steps, count the number of off-type heads/plants, inseparable other crop plants, objectionable weeds, and heads or plants affected by the designated disease.

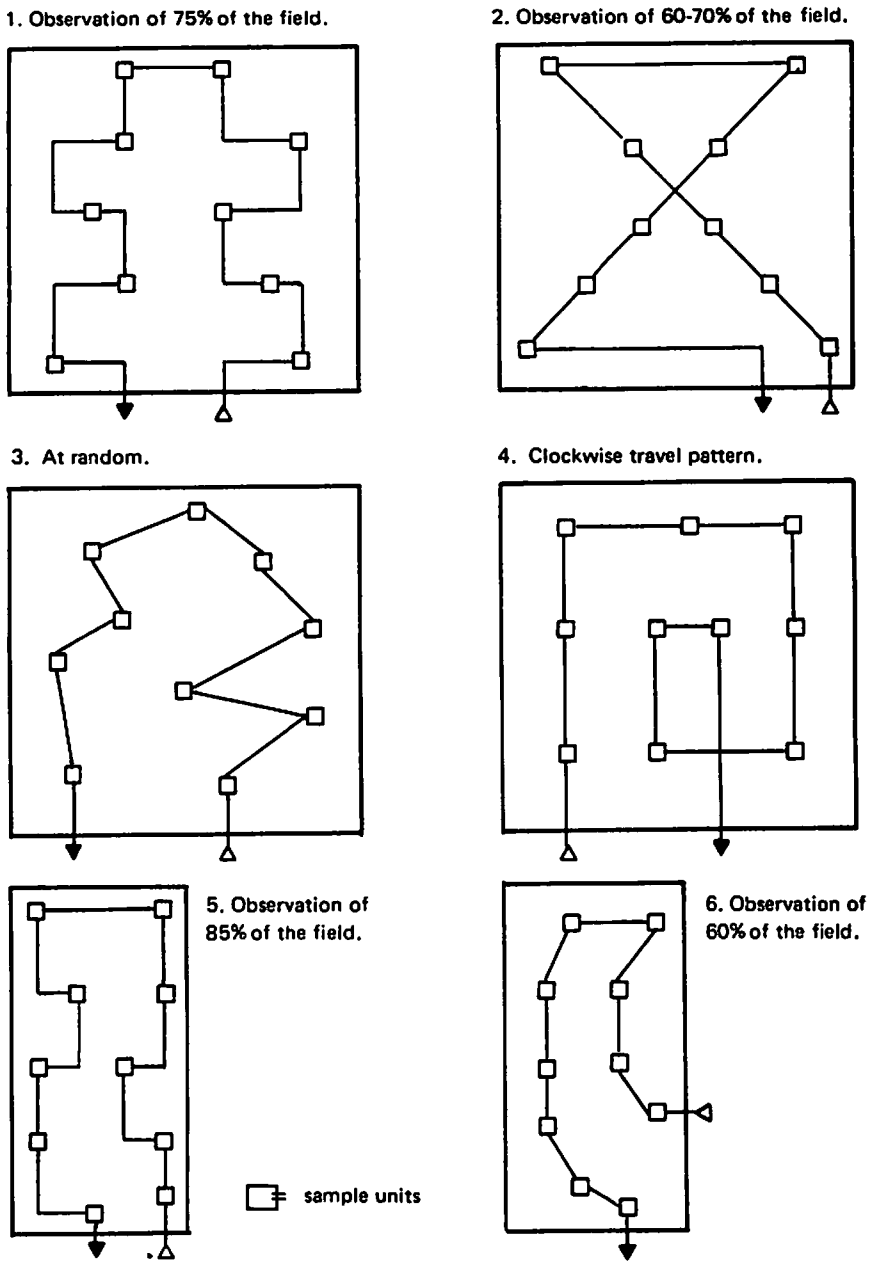

Fig. 1. Suggested travel patterns for field inspection (Svensson *et al.*, 1975).

Table 1. Specific requirements for field inspection.

Factor	Maximum permitted (%)*	
	Foundation	Certified
Off-types (earheads)	0.05	0.30
Inseparable other crop plants	0.01	0.05
Objectionable weed plants	0.01	0.02
Plants affected by seed-borne diseases	0.10	0.50

* Standards for off-types, inseparable other crops, and objectionable weeds should be met at the final inspection, and those for loose smut of wheat should be met at any inspection conducted between commencement of flowering and harvest.

Table 2. Seed standards for field inspection.

Factor	Standard	
	Foundation	Certified
Pure seed (min.)	98.0%	98.0%
Inert matter (max.)	2.0%	2.0%
Other crop seeds (max.)	10/kg	0.10%
Total weed seeds (max.)	10/kg	0.10%
Objectionable weed seed (max.)	2/kg	5/kg
Germination (max.)	85.0%	85.0%

6. Cross over the pre-determined number of rows and repeat the process as many times as required to include the desired number of plants or earheads. This completes one count.
7. Repeat the entire process until completing the number of counts required for the field size.

It is important that the seed field meets the minimum isolation requirements and conforms to other minimum field standards. If the field does not meet these standards at the first inspection, a second inspection may be made.

Reporting results:

The results of the field inspection must be filed (see Appendix) with the certification agency until the seed crop has been harvested, processed, sampled, and laboratory-tested and has met all quality requirements (seed standards) for certification. As an example, the minimum seed certification standard for wheat and barley is as follows:

Land requirements: A crop of barley or wheat is not eligible for certification if planted on land on which the same kind of crop was grown in the previous season, unless the previous crop was of the same variety and was approved by the certification agency as having certifiable standards of variety purity.

Field inspection: A minimum of two inspections shall be made between flowering and the time the crop is ready for harvest.

Field standards: A seed field should be separated by 3 m from fields of other varieties and fields of the same variety not conforming to varietal purity requirements for certification.

In addition to an isolation distance of 3 m, seed fields of wheat varieties susceptible to disease(s) shall not have within a prescribed distance any wheat field infected by that disease in excess of the prescribed standards.

For specific requirements, see Table 1; for seed standards, see Table 2.

References

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Aspects of Seed Quality Control

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The development of seed industries requires a great deal of time and effort. Countries with newly-established seed industries soon learn that testing and certification are integral facets of seed production. Seed quality control encompasses the following eight factors, which are described in detail.

1. Analytical purity (physical or mechanical purity)

Farmers require seed that is uncontaminated with seed of different crop species, pieces of straw, sand, and weed seeds. The degree of a seed lot's mixture with foreign material is determined with a manual test. Completely pure seed is the best, of course, but cleaning machines cannot usually remove all impurities, and as more and more impurities are removed, a greater amount of crop seed is lost in the process. Yet, cleaning is one of the most effective ways to upgrade seed quality, and inexpensive when compared with its benefits.

The purity test both determines the effectiveness of the cleaning operation and provides pure seed for the germination test. The laboratory purity test of a small sample determines the percentage by weight of intact seed of the species named on the label. Impurities include seeds of other crop species, weed seeds, and inert matter such as broken seeds, chaff, pieces of leaf, and soil particles. The percentages and types of all impurities are recorded, including the scientific names of seeds.

2. Content of other seeds

The degree of admixture with seeds of other species is determined by the number count test, giving only seed numbers per weight of seed examined. The test can be used for seeds of weeds or other crops, or for both, when the purity test is not sufficiently precise. The purity test percentage is expressed to the nearest 0.1%, which equals the occurence in the sample of two or three seeds similar in size to the pure seed. When barley occurs as an impurity in wheat, for example, one or two seeds would be noted, but might not be reported as a separate percentage. Furthermore, the analyzed sample is so small that significant impurities may be missed altogether. In cereals, the sample is about 0.001 of the quantity of seed sown on a hectare, so the wheat seed could contain about a thousand barley seeds that might not appear in the analyzed sample.

When it is especially important to avoid contamination, a sample 10 times larger than that used for the purity test is examined and the number of seeds of other species is counted. The result is then expressed as the number of seeds over the weight of seed examined; e.g., 2/kg.

The test is also used to determine the degree of contamination with weed seeds. All farmland is infested with weed seeds, and some weed seeds in the sowing seed are not harmful. However, certain seeds should be completely absent from sowing seed, including those of noxious weeds such as wild oats and parasitic plants like *Orobanche*, *Cuscuta*, and *Striga*. On the other hand, cleavers (*Galium aparine*) are acceptable at low levels, but may be very harmful at higher levels at which they are highly competitive, promote collapse of the crop, and become mixed again with the seed of the harvested crop.

Weed seeds are best expressed as the number of seeds in the weight of seed examined, partly for the same reasons that seeds of other crop species are best expressed this way, and partly because weed seeds differ so much in size that a percentage by weight can be meaningless. The very small seeds of loose silky bentgrass (*Apera spica-venti*), for instance, will give rise to plants as tall and harmful as wild oat species (*Avena fatua*, *A. sterilis*, and others). Only 1% of silky bentgrass in a 1 kg cereal sample may represent as many as 100,000 seeds, while 1% wild oats represents only 500 seeds. It is clear that it is not the weight of weed seeds sown that is important, but the number.

3. Cultivar purity

This aspect of quality is best controlled in the field by inspection and tested in field plot tests, because a cultivar can be

identified more accurately by examining growing plants rather than dry seed in the laboratory. Cultivar certification schemes have been established in which the mother plants are inspected in a general way in the production farm's fields, while a plot near the laboratory is sown with the same seed for more careful examination. Cultivar purity determined this way, however, is not as reliable as a theoretical laboratory test of a sample from bags actually supplied to the farmer. Unfortunately, there are few reliable laboratory tests, so they must be supplemented by control of the source of the seed sown for multiplication.

4. Germination capacity

This is the percentage of pure seeds that produce normal seedlings in a laboratory test; abnormal seedlings are not included in the germination percentage. The germination percentage indicates the potential of a seed lot to establish seedlings under good field conditions. Most field conditions are not optimal, however, and even if they are, some seeds will still be attacked by rodents, birds, or insects; or will fall on or under a stone; or will fail to grow because of weed competition. Although most seed lots will not reach the predicted value, seed lots with a higher germination capacity will always prove to establish more seedlings than those with a lower germination capacity, especially under suboptimal conditions.

Germination capacity is one of the most important characteristics to examine when buying seed. Since the germination test is carried out on pure seed prepared during the purity test, and because pure seed does not represent the seeds in the bag, the combination of germination and purity, the "pure live seed content" (PLS), is the criterion used to express the quality of a seed lot. In a lot with 90% purity and 80% germination, PLS = 90 x 80/100 = 72; in other words, only this proportion of the mass in the bag can produce normal seedlings. To judge which seed is the best buy, the price paid for seed should be calculated as price per unit of PLS.

5. Vigor

While germination capacity represents the ability to produce seedlings under good field conditions, vigor represents the capacity under poor conditions. Lots with the same germination capacity may perform quite differently under adverse or suboptimal field conditions, especially those with low germination capacity.

A general rule is that high germination capacity is associated with high vigor, and if there is not an appropriate vigor test, only lots

with high germination capacity should be bought. Vigor may be reduced by damage to the embryo or seed coat during harvesting and processing. Other factors affecting vigor include environment and nutrition of the mother plant, stage of maturity at harvest, seed size, senescence caused by long storage, and pathogens. Discrepancies between germination capacity and field performance are not equally important in different species; in pulses, for instance, discrepancies occur much more commonly than in cereals.

6. Moisture content

This should also be taken into account when buying seed. As seed is mostly traded by weight, moisture content indicates the amount of water purchased; 1% greater moisture in a lot of 10 tonnes represents 100 kg of water that could have been seeds by weight. During production, moisture content should be kept low at all stages to prevent fungal development and to limit insect growth. On the other hand, extremely low levels of moisture content may cause germination problems, such as inducing secondary dormancy.

Moisture content is the main determinant of whether seed will keep its germination capacity from harvest to sowing. The laboratory moisture test can be carried out simply and accurately. In seed stores and during processing, portable moisture meters can help to make quick, on-the-spot assessments of moisture.

7. Health

In certain crops, seed health is an important factor in the control of crop diseases and field establishment. "Seed-borne diseases" are those transmitted by seeds. Different diseases develop in different ways; for instance, the symptoms of cereal smut and bunt diseases do not appear until the flowering stage, when they then spread the infection throughout the crop. Seedlings infected with such diseases usually do not show any abnormality. Other diseases such as cereal leaf-stripe and root-rot affect the seedlings early by limiting their growth or by killing them; then, the infection spreads and the remaining plants produce infected seeds. Seed infected with this category of pathogens may produce abnormal seedlings, but their actual effect on seedling establishment in the field cannot be predicted sufficiently by the standard germination test, so special seed health tests are required.

Seeds may also carry viruses such as mosaic or leaf-stripe which do not usually affect seedlings, but which may be infectious and passed on to other plants by insects such as aphids long before symptoms appear.

Chemical treatment should be used only as a last resort; a good field inspection for diseases is better than seed tests because symptoms usually appear clearly on the plants. Any inspected lots showing disease should be discarded if the type and level of disease are severe. It is possible to identify most pathogens in the laboratory, although diagnostic techniques may be very complicated; for example, pathogenic fungi are often difficult to distinguish from totally harmless saprophytic species. An experienced pathologist able to distinguish between innocent and harmful fungi must supervise the testing. It is extremely important that such tests be carried out with the same degree of exactitude year after year; this is one reason why seed health tests are beneficial only in the more advanced seed industries.

8. Size and uniformity of size

In many species, small seeds are inferior to large ones because they produce smaller seedlings that are less competitive, affected earlier by disease, and lower-yielding. In many crops, such as cereals, smaller seeds are often shrivelled because they were immature at harvest or were produced by diseased plants. At any rate, all material that passes through the bottom screens of cleaning machines should not be sown, although the certifying authority may prescribe a smaller screen size in years when seeds are in short supply. Laboratory sieving machines can be used to check whether a lot meets the standards. The farmer may be interested to know how many seeds are sown in a quantity of one kilogram, which can be estimated easily from the weight of a thousand seeds.

Uniformity of size is also related to planting method. The importance of uniformity increases from hand planting to automatic broadcasting, and again to automatic planting in rows, and still further when precision planting is used.

Organizations that Develop Quality Control Methods

International Seed Testing Association (ISTA)

The ISTA was established in 1924 to promote uniformity of seed testing, in order to facilitate the international trade of seeds. ISTA rules describe how to test seed for an international ISTA certificate. ISTA certificates are widely used, especially in international

agriculture in which the certificate is a kind of "seed passport" and a guarantee for banks in settling international payments. About 60 countries belong to the ISTA, and the number is increasing mainly because developing countries are establishing seed testing stations that fulfill the requirements for accreditation. There are now some 130 accredited stations allowed to issue international certificates. ISTA does not fix standards; rather, it prescribes methods of sampling, sealing, and testing for issuing an ISTA certificate. Membership is not limited only to accredited stations, and individuals can subscribe to the official ISTA journal, *Seed Science and Technology*, and to many other ISTA publications.

Organization for Economic Cooperation and Development (OECD)

OECD launched its certification scheme in 1958. The organization now includes 30 member countries, with a scheme for all major crop species. Like ISTA, OECD mainly defines procedures and grade names (such as pre-basic seed and basic seed). When a seed lot has been certified in accordance with OECD's directions, it is entitled to the OECD label which is recognized by the customs authorities of participating countries. Member countries adapt their national certification schemes to comply with OECD directives.

Young seed industries which are not yet OECD or ISTA members should follow the procedures of the two organizations as closely as possible with an eye toward future membership.

Seed Sampling

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Introduction

The object of seed sampling is to obtain a sample of a size suitable for tests, with the same constituents in the same proportions as in the seed lot.

The seed sample tested in the laboratory is minute compared to the seed lot it represents (e.g., if 1 g is analyzed from a 10,000 kg lot, the ratio is 1:10,000,000). To obtain uniform, accurate results in seed testing, it is essential that samples be prepared in accordance with the rules of the International Seed Testing Association (ISTA). It is essential that the sample precisely represents the composition of the seed lot, and that the working sample obtained in the laboratory represents the submitted sample.

ISTA rules for sampling must be followed by seed testers, inspectors, and warehouse samplers, so the seed testing station authorized by ISTA can issue international green or orange certificates; otherwise, only the less valuable blue certificate can be issued.

Certificates

Although various national certificates exist, three international ISTA certificates (described in detail in the *ISTA Rules*, chapter two) are most important for the seed trade:

1. *The Orange Seed Lot Certificate*, issued when sampling has been done according to ISTA rules by an official body approved by the seed testing station. The sampling and testing must have been carried out in the same country.
2. *The Green Seed Lot Certificate*, with the same requirements as the orange, but with testing carried out by an authorized station in a country other than where the lot was sampled.
3. *The Blue Seed Sample Certificate*, only referring to the sample. This certificate is used with unofficial sampling, when the seed testing station is not certain that the sample represents the seed lot. The certificate only refers to the quality of the sample received, and omits the name of the sampling and sealing agency as well as the lot's mark and seal.

Definitions

Lot: A specified quantity of seed, physically identifiable, for which an International Analysis Certificate may be issued.
Primary sample: A small portion taken from one location in the lot.
Composite sample: A mix of all the primary samples from the lot.
Submitted sample: The sample submitted to the testing station, comprising the composite sample reduced as necessary (since the composite sample is usually much larger than tests require). It must be at least as large as the size specified in ISTA Rule 2.6.3
Working sample: A reduced sample taken from the submitted sample in the laboratory, used in a given quality test.
Sealed: A sealed container, for both lots and samples, is one that is closed in such a way that it cannot be opened and closed again without either destroying the seal or leaving evidence of tampering.

Principles and Procedures for Sampling the Lot

A lot that is to be sampled must not show any heterogeneity, which means that all primary samples must be exactly the same in aspect. If there is evidence of heterogeneity (which can be confirmed with the heterogeneity test, ISTA Rule 2.4.2.A), sampling should not be carried out.

The size of the lot must not exceed certain limits (Table 1, column 2, subject to a tolerance of 5%). For most agricultural seeds, the lot must not exceed 10,000 kg, but for large-seeded species, 20,000 kg is allowed. An exception is maize, for which 40,000 kg is allowed.

Table 1. Lot and sample weights.

Species	Maximum weight of lot (kg)	Minimum sample weights (g)		
		Submitted sample	Working sample for purity analysis	Working sample for count of other species
1	2	3	4	5
Arachis hypogaea L.	20,000	1000	1000	1000
Avena sativa L.	20,000	1000	120	1000
Cicer arietinum L.	20,000	1000	1000	1000
Glycine max (L.) Merrill	20,000	1000	500	1000
Hordeum vulgare L.s.l.	20,000	1000	120	1000
Lens culinaris Medik.	10,000	600	60	600
Medicago arabica (L.) Huds. (in bur)	10,000	600	60	600
Medicago arabica (L.) Huds. (out of bur)	10,000	50	5	50
Medicago littoralis Rohde ex Lois.	10,000	80	8	80
Medicago lupulina L.	10,000	50	5	50
Medicago orbicularis (L.) Bartal.	10,000	80	8	80
Medicago polymorpha L.	10,000	70	7	70
Medicago sativa L.	10,000	50	5	50
Medicago scutellata (L.) Miller	10,000	450	45	450
Medicago truncatula Gaertn.	20,000	120	12	120
Oryza sativa L.	20,000	400	40	400
Pennisetum glaucum (L.) R. Br.emend. Stunz	10,000	150	15	150
Phaseolus coccineus L.	20,000	1000	1000	1000
Phaseolus lunatus L. (incl. *P. limensis* Macfad.)	20,000	1000	1000	1000
Phaseolus mungo L.	20,000	1000	700	1000
Phaseolus radiatus L.	20,000	1000	120	1000
Phaseolus vulgaris L.	20,000	1000	700	1000
Pisum sativum L.s.l.	20,000	1000	900	1000
Secale cereale L.	20,000	1000	120	1000
Sesamum indicum L.	10,000	70	7	70
Sorghum almum Parodi	10,000	200	20	200
Sorghum bicolor (L.) Moench	10,000	900	90	900
Sorghum halepense (L.) Pers.	10,000	90	9	90
Sorghum sudanense (Piper) Stapf	10,000	250	25	250
Trifolium alexandrinum L.	10,000	60	6	60
Trifolium campestre Schreb.	10,000	25	0.5	5
Trifolium dubium Sibth.	10,000	25	2	20
Trifolium fragiferum L.	10,000	40	4	40
Trifolium glomeratum L.	10,000	25	1	10
Trifolium hirtum All.	10,000	70	7	70

Trifolium hybridum L.	10,000	25	2	20
Trifolium incarnatum L.	10,000	80	8	80
Trifolium lappaceum L.	10,000	25	2	20
Trifolium pratense L.	10,000	50	5	50
Trifolium repens L.	10,000	25	2	20
Trifolium resupinatum L.	10,000	25	2	20
Trifolium subterraneum L.	10,000	250	25	250
Triticosecale spp.	20,000	1000	120	1000
Triticum aestivum L. emend. Fiori et Paol.	20,000	1000	120	1000
Triticum durum Desf.	20,000	1000	120	1000
Vicia benghalensis L.	20,000	1000	120	1000
Vicia faba L.	20,000	1000	1000	1000
Vicia pannonica Crantz	20,000	1000	120	1000
Vicia sativa L. (incl. V. angustifolia L.)	20,000	1000	140	1000
Vicia villosa Roth (incl. V. dasycarpa Ten.)	20,000	1000	100	1000
Vigna marina (Burm.f.) Merr.	20,000	800	80	800
Vigna unguiculata (L.) Walp. (incl. V.sinensis (L.) Saviex Hassk.)	20,000	1000	400	1000
Zea mays L.	40,000	1000	900	1000

Another sampling requirement is that the lot must be in sealed or sealable bags or other containers that are labelled or marked for identification with a single lot designation. An International Seed Lot Certificate cannot be issued for seed that is loose or stored in unsealable containers.

At the time of sampling, all containers must bear a lot identification corresponding to that of the certificate. The sampler must seal or supervise the sealing of the containers.

Various instruments are allowed for sampling. A common instrument is the *stick or sleeve-type trier*: a hollow brass tube inside a closely-fitting outer shell or sleeve with a solid pointed end. When the slots in the tube and sleeve walls are aligned, seeds can flow into the tube cavity; a half-turn of the tube closes the openings. Tubes are designed for different kinds of seed and various container sizes, so they vary in length and diameter, and are made with or without partitions. In sampling cereal seed in bags, a $\pm$760 mm trier with an outside diameter of $\pm$25 mm and six slots is suitable.

Bin samplers are constructed the same way but are much larger, ranging up to 1600 mm (1.6 m) in length and 38 mm in diameter with six or nine slots. The trier may be used horizontally or vertically. A trier for vertical use must have partitions dividing it into compartments, or the seed will drop into the sampler from the upper layers when the trier is opened, giving excess seed from these layers. When using a stick sampler vertically, some dragging of seeds from the top towards the bottom is unavoidable, but this can be reduced with a trier that is smooth and has as few ribs as possible.

Whether used vertically or horizontally, the trier should be inserted diagonally into the bag or container. (For bulk seed, vertical insertion is more practical.) The closed trier is thrust into the bag, then opened and turned a couple of times both vertically and horizontally or gently agitated to allow it to fill completely. Then it is closed again, withdrawn, and emptied into a suitable pan such as a pipe cut lengthwise, or into a piece of waxed paper or similar material. The trier should be closed carefully without damaging the seeds.

A stick trier up to a certain diameter may be inserted through sack walls or coarsely woven jute or similar material. When the trier is removed, the point should be run across the hole a couple of times both vertically and horizontally to pull the threads together and close the hole. Closed paper bags may also be sampled by puncturing the bag and sealing the hole later with an adhesive patch.

Another type of trier, the *Nobbe trier*, is suitable only for sampling bags. It is a pointed tube long enough to reach the center of the bag, with an oval hole near the pointed end. For cereals, the distance from hole to handle should be about 350 mm and the internal diameter of the tube should be about 14 mm. The trier should be inserted gently into the bag, pointing upwards at an angle of about 30°, with the hole facing downwards until it reaches the center of the bag. Then it is revolved 180°, bringing the hole face upwards, and is withdrawn with decreasing speed so that the quantity of seed obtained from successive locations increases progressively from the center to side of the bag. Seed will then pour out of the open handle while agitated. Alternatively, a trier long enough to penetrate to the far side of the bag should be withdrawn at a relatively constant speed. While the trier is being withdrawn, it should be gently agitated to maintain an even flow of seed. The more polished the inner surface of the trier, the more freely seed will flow.

Sampling should alternate between the top, middle, and bottom of bags. A bag on the floor can be placed atop other bags to sample the bag bottom.

For certain species, especially chaffy and non-free-flowing species (mainly grasses), *hand sampling* is sometimes the most satisfactory, although it is difficult to sample deeper than about 40 cm, and thus impossible to obtain samples from the lower layer of bags and bins. The sampler may have some bags partly or completely emptied to facilitate sampling, and then refilled. When sampling is done by hand, fingers should be tightly closed around the seeds so that seeds do not drop out.

For seed lots in bags of uniform size (or other containers of similar capacity), there are minimum required sampling intensities. For 1 to 5 containers, each container should be sampled and at least

five primary samples taken. For 6 to 30 containers, at least 1 in every 3 containers should be sampled, but never fewer than 5. For 31 or more, at least 1 in every 5 containers should be sampled, but never fewer than 10. ISTA Rules describe sampling intensities for bulk seed, for seed in containers of different or very small sizes, and for streams of seed entering containers.

If the primary samples appear uniform, they should be mixed to form the composite sample, from which the submitted sample is taken by one of the laboratory methods referred to below, using larger equipment if necessary. If it is difficult to mix and reduce the sample properly in the warehouse, the entire composite sample should be forwarded to the seed testing station for reduction. A composite sample of appropriate size may be used as the submitted sample without reduction.

Submitted samples must be identified with their lot designation. Samples should be packed to prevent damage during transit and not in moisture-proof containers. Bags of cotton, linen, or very tough paper are suitable. If moisture content is to be determined, a second sample must be packed separately in a moisture-proof container excluding as much air as possible.

Samples should be sent quickly to the seed testing station and never be left with the owner, applicant, or others not authorized by the sampling agency or by the seed testing station.

Principles and Procedures for Laboratory Sampling

Several methods and apparatus are used to reduce the submitted sample to the size of a working sample (for minimum weights of the working sample, see Table 1, column 4). Of the methods described, method 5, a combination of 1 and 4, is appropriate for testing a large number of different species, especially small-seeded species.

Mechanical divider method

Three machines can be used: the conical divider (Boerner type), the soil divider (Riffle type), and the centrifugal divider (Gamet type). All three divide a given quantity of seed into two approximately equal portions. The sample can be mixed by passing it through the divider, recombining the two portions, and passing the whole sample through a second or even third time if necessary. The sample is reduced by passing the seed through repeatedly and removing half on each run. This process of successive halving is continued to obtain a working sample of approximately, but not less than, the required size.

Modified halving method

The apparatus comprises a tray fitted with a grid of equal-sized cubical cells which are open at the top. Every second cell has an open bottom. After preliminary mixing, the seed is poured evenly over the grid, which is lifted to leave approximately half of the sample on the tray. The process is repeated to obtain a working sample of approximately, but not less than, the required size.

Random cups method

In this method, six to eight small cups are placed at random positions on a tray. After preliminary mixing, the seed is poured uniformly over the tray and the seed that falls into the cups is the working sample. For a particular group of similar species, a certain size cup is needed. At least six cups should be taken, but if the minimum weight is not yet attained, a seventh or eighth cup can be added.

Spoon method

This method, requiring a tray, a spatula, and a spoon with a straight front edge, is permitted only for small-seeded species, and never for seed mixtures. After preliminary mixing, the seed is poured evenly over the tray, which must not be shaken afterwards. The spoon in one hand and the spatula in the other are used together to remove small portions of seed from not less than five random places. Seed portions should be sufficient to constitute the working sample. This method never yields too few seeds nor far too many, saving time spent on excessive analysis later.

Combined divider-spoon method

This method combines the benefits of two methods: the rapid reduction in size allowed by the mechanical divider (any of the three types), and the accuracy of the spoon method. This method allows a laboratory to efficiently sample a large variety of species.

Duplicate Analysis

To improve accuracy and at the same time to check the analysis, two independent working samples, each half of the prescribed weight, should be taken and analyzed by different analysts. Results can be considered valid when both fall within the tolerance limits given in Table 2, column 3.

Table 2. Tolerances for purity tests.* This table indicates tolerances for comparing duplicate working samples from the same submitted sample for any component or a purity sample, for either chaffy or non-chaffy seed. The probability is 0.05. It is calculated from data obtained in a co-operative investigation of variation between actual purity tests carried out in USA and Canada (Proc. Int. Seed Test. Ass. 25, 102, 1960).

Average analysis of two half samples or two whole samples		Tolerances for differences between	
		Half working samples	Whole working samples
1	2	3	4
99.95-100.00	0.00- 0.04	0.23	0.16
99.90- 99.94	0.05- 0.09	0.34	0.24
99.85- 99.89	0.10- 0.14	0.42	0.30
99.80- 99.84	0.15- 0.19	0.49	0.35
99.75- 99.79	0.20- 0.24	0.55	0.39
99.70- 99.74	0.25- 0.29	0.59	0.42
99.65- 99.69	0.30- 0.34	0.65	0.46
99.60- 99.64	0.35- 0.39	0.69	0.49
99.55- 99.59	0.40- 0.44	0.74	0.52
99.50- 99.54	0.45- 0.49	0.76	0.54

99.40- 99.49	0.50- 0.59	0.82	0.58
99.30- 99.39	0.60- 0.69	0.89	0.63
99.20- 99.29	0.70- 0.79	0.95	0.67
99.10- 99.19	0.80- 0.89	1.00	0.71
99.00- 99.09	0.90- 0.99	1.06	0.75
98.75- 98.99	1.00- 1.24	1.15	0.81
98.50- 98.74	1.25- 1.49	1.26	0.89
98.25- 98.49	1.50- 1.74	1.37	0.97
98.00- 98.24	1.75- 1.99	1.47	1.04
97.75- 97.99	2.00- 2.24	1.54	1.09
97.50- 97.74	2.25- 2.49	1.63	1.15
97.25- 97.49	2.50- 2.74	1.70	1.20
97.00- 97.24	2.75- 2.99	1.78	1.26
96.50- 96.99	3.00- 3.49	1.88	1.33
96.00- 96.49	3.50- 3.99	1.99	1.41
95.50- 95.99	4.00- 4.49	2.12	1.50
95.00- 95.49	4.50- 4.99	2.22	1.57
94.00- 94.99	5.00- 5.99	2.38	1.68
93.00- 93.99	6.00- 6.99	2.56	1.81
92.00- 92.99	7.00- 7.99	2.73	1.93
91.00- 91.99	8.00- 8.99	2.90	2.05
90.00- 90.99	9.00- 9.99	3.04	2.15
88.00- 89.99	10.00-11.99	3.25	2.30
86.00- 87.99	12.00-13.99	3.49	2.47
84.00- 85.99	14.00-15.99	3.70	2.62
82.00- 83.99	16.00-17.99	3.90	2.76
80.00- 81.99	18.00-19.99	4.07	2.88
78.00- 79.99	20.00-21.99	4.23	2.99
76.00- 77.99	22.00-23.99	4.37	3.09
74.00- 75.99	24.00-25.99	4.50	3.18
72.00- 73.99	26.00-27.99	4.61	3.26
70.00- 71.99	28.00-29.99	4.71	3.33
65.00- 69.99	30.00-34.99	4.86	3.44
60.00- 64.99	35.00-39.99	5.02	3.55
50.00- 59.99	40.00-49.99	5.16	3.65

*This table is Table 3A of the ISTA Rules, 1985.

Seed Testing and Quality Control in The Netherlands

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The Government Seed Testing Station in the Netherlands belongs to the Directorate of Arable Farming and Horticulture of the Ministry of Agriculture and Fisheries. The other research stations in the directorate cover arable farming and field production of vegetables, horticulture under glass, floriculture, arboriculture, bulbs, fruit, and mushrooms. The research institutes dealing with special disciplines, such as breeding, phytopathology, mechanization, and soil science, belong to the Directorate of Agricultural Research of the Ministry of Agriculture and Fisheries.

Main Activities of the Seed Testing Station

The Seed Testing Station has a number of functions. It performs quality analysis of cleaned seed samples from the seed trade and issues analysis certificates, including International Seed Testing Association (ISTA) analysis certificates (for moisture, purity, germination, and seed health). It also carries out quality analysis of uncleaned samples of contract-grown seed lots, and develops and improves analysis methods, in cooperation with ISTA. Other functions include research on seed problems, giving advice on seed handling, and training in seed testing and seed technology. The station also assists in different aspects of seed industry development in developing countries.

The research conducted by the Seed Testing Station aims to simplify routine screening and analysis, and also to solve basic problems of the

seed industry. About 70 staff members work at the station, with more than 50% involved in routine testing. The station tests about 23,000 samples per year (7,500 for contract grown seed lots, which arrive uncleaned, and 15,500 for trade samples, which arrive already cleaned). The station is divided into one department for cleaning, purity, identification, and cytology; another for germination, storage, packing, and moisture; and others for seed health, certification, and administration.

History and Procedure of Seed Testing

Good quality seed is essential for good crop production; cultural practices cannot compensate for poor quality seed. To guarantee quality, seed testing is necessary.

Seed testing started in 1864 in Germany, followed in 1877 by the Netherlands. Quality control was first restricted to external appearance and origin of the seed, but was soon followed by purity and germination testing, which are currently the main standards for seed evaluation. Testing is also done for cleanliness, presence and kind of weeds, seed moisture, presence of pathogens, etc. Quality control in seed production, testing, certification, and marketing starts in the field and continues in seed testing laboratories.

The Netherlands Inspection Services (NAK) cooperates closely with the Seed Testing Station. Both can issue certificates, but only the station is authorized to issue international certificates for export in accordance with ISTA rules.

Field inspection is always done by the certifying agencies: the Netherlands Inspection Services (NAK) for agricultural seeds (including seed potatoes), and the NAKG for vegetable and flower seeds. The NAK (NAKG) is a farmer/grower foundation, partly subsidized by the government for seed testing analysis. Agricultural seed for domestic use is mainly tested in regional NAK laboratories. Horticultural seed is mainly tested in the NAKG laboratory, which guarantees good seed quality with an NAKG certificate. If an international certificate is required, the sample must be tested by the Seed Testing Station.

In addition to these certificates, there is the International Phytosanitary Certificate issued only by the Plant Protection Service (a government institute). Testing is done by the Seed Testing Station for agricultural and some horticultural seeds, and by the Service for horticultural seeds.

Developments in Seed Testing

Purity investigation is an important aspect of seed quality evaluation. Impurities in a seed lot include seeds of other crop

species, weed seeds, and inert matter such as broken seeds, chaff, pieces of leaf, and soil particles. The identification of seed of other crops and weeds requires a thorough knowledge of seed taxonomy. The Seed Testing Station conducts a two-year seed taxonomy training course in its laboratory, and also advises workers in seed firm laboratories.

The requirements for purity have stimulated the development of seed cleaning. The station has a cleaning laboratory with small scale machinery that gives results comparable to those from cleaning plants. In modern cleaning plants, the goal is to produce very pure seed with minimum loss of good seed and at reasonable expense. Cleaning machines are not able to remove all impurities, however, because the more impurities removed, the more crop seed removed. Cleaning is nevertheless vital to ensure production of good quality seed, and a high purity requirement is justified, but demands should not be unduly strict.

Another important quality aspect is seed germination. The germination test is done in the laboratory under favorable germination conditions. In the official test, the distinction between normal and abnormal seedlings is very important. The figures obtained in the laboratory test and field emergence are generally closely related. Each kind of seed behaves differently with regard to temperature, light, and moisture. Seed is often dormant and must be activated before determining the actual germination capacity. The problems of germination biology, seed dormancy, seedling abnormality, and seed vigor, as well as packing and storage conditions, require further research.

Control of seed health is also very important in testing for seed quality. A number of plant diseases can be seed-transmitted, including fungal, bacterial, and viral diseases. A disease may also be seed-borne, which is of special concern to the health department. A disease in a given crop can also be air- or soil-borne, depending mainly on the biology of the pathogen. The significance of seed transmission of pathogens was underestimated in earlier years, but the demand for seed-health testing is now increasing, because even minor occurrence of a pathogen in a seed lot may cause severe crop damage.

International Cooperation

It is important for international trade that the same seed-testing methods are used worldwide. The European Seed Testing Association, founded in 1921, was changed in 1924 to the International Seed Testing Association. At present, the ISTA accredits 136 official seed testing

stations in 59 countries. These stations, which test samples in accordance with the very detailed ISTA rules, have the right to issue ISTA analysis certificates. International trade primarily uses the orange ISTA seed lot certificate.

There are several ISTA technical committees with members from different countries who contribute through research, referee testing, and discussions to improvement of international agreements and rules. Committees cover rules, germination, purity, moisture, storage, plant diseases, equipment, and other topics.

Relationship Between Breeding and Seed Testing

Seed quality testing has a role in development of new varieties. Each phase in the production of seed of a new variety (breeder seed, basic seed, and certified or commercial seed) has a specific seed quality requirement. Seed quality, in relation to storage conditions and germinability, is also important in the operation of gene banks.

Testing for Genuineness of Varieties: Some Special Laboratory Methods

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Introduction

To produce pure seed for consumer use, the breeder seed--which should be 100% pure and true to variety--is multiplied for several generations. During multiplication, deterioration will take place due to:

- genetic factors such as unwanted cross-fertilization, natural mutation, and segregation of insufficiently pure material;
- contamination from the field with seeds of other crops, varieties, and weeds;
- contamination from drills, combines, trailers, etc.;
- contamination from seed processing.

Problems can also arise during field inspection, transport, processing, and labelling, but the chance of deterioration is lower with fewer generations and stricter control.

After seed is produced, it is often checked to establish whether the seed lot is of the variety indicated (genuineness of variety) and whether the variety is sufficiently pure (varietal purity).

Testing for Genuineness and Varietal Purity

For the test of genuineness, it is assumed that the varieties are distinct, uniform, and stable, based upon morphological, physiological,

cytological, chemical, and other traits. Upon release, varieties are described using these types of characteristics, and the test for genuineness establishes whether the variety still conforms to its original description.

Examinations may be carried out on seeds, seedlings, or mature plants. When testing genuineness, a standard sample that represents the variety should always be used. It is sometimes possible to identify the variety in the dry seed stage, but seedlings and/or mature plants must be studied in many cases. If many different varieties are available, differences between them tend to become smaller, often making it more difficult to distinguish varieties based on seed characteristics.

Variety Categories

Varieties fall into three categories: those of vegetatively-propagated, self-pollinated, and cross-pollinated species. All plants of a vegetatively-propagated variety are alike. Varieties of self-pollinated species are usually homozygous, with all plants more or less alike; not much variation and segregation occurs. The majority of the variation results from environmental conditions. Many self-pollinated species have a small percentage of outcrossing, resulting in variation.

Varieties of self-pollinated and vegetatively-propagated species are often not difficult to describe, so the test for genuineness of variety is relatively easy. Individuals of varieties of cross-pollinated species, however, are not alike and the population has a certain equilibrium with regard to gene frequency. Testing for genuineness is therefore more difficult and must often rely upon segregation percentages.

Characteristics

The tests can be based on any characteristic that can be used to distinguish between varieties and species, but the most easily observable characteristics--clear morphological differences--are preferred. It is also better to use characters that are less influenced by environmental conditions. The traits are generally the same types in all species, but each species has its own particular characteristics. The International Union for the Protection of New Varieties of Plants (UPOV) and the Organization for Economic

Cooperation and Development (OECD 1971) have developed lists of characteristics which can be used to test for genuineness in different species. ISTA (1973), Hervey-Murray (1980), and Milatz (1970) describe such characteristics in greater detail than this chapter, which deals only with a number of special laboratory methods used to test for varietal genuineness in seeds and seedlings.

Special Laboratory Methods

The special laboratory methods (Andersson 1984; ISTA 1973; ISTA 1985; RPvZ 1964; McDonald 1985) include the application of UV light, the application of chemicals, chromosome counts, and biochemical tests.

UV light

Some seeds fluoresce in UV light (longwave UV radiation close to the UV area; NUV light). Examples are:

- oat: yellow oat seeds absorb UV light, but seeds of white-seeded varieties fluoresce clearly in UV light. The color of the grain under UV light can also be diagnostic in *Hordeum*.
- pea: UV light is used to distinguish between garden and fodder pea, since fodder pea seeds do not fluoresce.
- *Vicia faba*: The testa of some varieties clearly fluoresce in UV light (Wesemann 1962).

Another method uses the exposure of germinating seeds to UV light. Examples are:

- *Lolium: L. multiflorum* (Italian ryegrass) seeds can be distinguished from *L. perenne* (English ryegrass) since the roots of the first species produce substances which fluoresce in UV light (Dales 1953).
- *Festuca: F. rubra* (red fescue) roots fluoresce yellow-green (in an atmosphere containing ammonia), whereas *F. ovina* roots fluoresce bluish-green (Linder 1958; van der Burg and Vierbergen 1979).
- *Allium:* Seedlings of *A. cepa* (onion) produce substances which fluoresce yellow, whereas *A. porrum* (leek) and *A. fistulosum* (Welsh onion) fluoresce bluish. *A. cepa* and *A. porrum* can be distinguished by their root substances which fluoresce in an atmosphere containing ammonia.
- *Beet:* Roots of different varieties may fluoresce differently (Eifrig and Kamra 1960).
- *Trifolium* and *Medicago* species.

Chemicals

Sodium hydroxide (NaOH): This chemical can be used to differentiate between red and white wheat (grain color). Seeds are submerged for 15-20 minutes in a 10% sodium hydroxide solution. After drying, the grains of red wheat are a clear red; white wheat grains are white-yellow.

This test is used only when the grains are difficult to differentiate between because of weather damage or seed treatment. Usually the characteristic grain color can be evaluated easily with the naked eye.

KOH bleach solution: A 1:5 solution of KOH and household bleach (5.25% NaOCl) may be used to differentiate between varieties of sorghum. Seeds are soaked for 5-10 minutes in the solution; seeds with tannic acid in the testa (or undercoat layer) darken, whereas seeds without tannic acid remain light.

Potassium dichromate: A 1% $K_2Cr_2O_7$ solution may be used to distinguish between seeds of garden and fodder pea; sodium hydroxide may also be used.

Lugol's solution: This solution (iodine + potassium + water) is used to distinguish between *Lupinus* varieties, based on the presence or absence of alkaloids (Bevas 1963).

HCl: The HCl test can be used to differentiate between yellow and white oats when the fluorescence test is not reliable, as with seeds that are weather-damaged or treated.

HCl may also be used to differentiate between the seeds of cucumber (*Cucumis sativus*) and melon (*C. melo*). Seeds are treated with a 1N HCl solution for 1½ -2 hours; melon seeds become more strongly colored (orange-yellow) (Steinberger 1961).

A 1% solution of HCl (or NaCl) is also used to intensify the coloration of cereal coleoptiles. The solution is added to the filter paper on which the seeds are growing.

Coloration of the aleurone layer: Beneath the testa, the barley grain has an aleurone layer which may contain chromoplasts; these can be colored with a chemical test (Day 1977), which entails soaking them 12-16 hours in 50% sulphuric acid, and then for four hours at 40°C in a solution of 10% HCl (33%) and 90% methanol.

DDT: Seedlings of various cereal varieties react differently to DDT. Seedlings at the two-leaf stage are sprayed with DDT suspension, and

again one week later. Certain varieties develop chlorosis (or die), whereas other varieties are unaffected. This method is not often used because DDT is considered a dangerous chemical and is banned in many countries.

Chromosome counts

In plants with different ploidy levels (grass, beet, wheat), counting the number of chromosomes in the root tips is the most conclusive way to differentiate between varieties with different ploidy levels. This method, however, is rather time-consuming and difficult.

The size of the seed often indicates the ploidy level, so grading seeds into different size fractions can separate varieties with different ploidy levels. Counting the number of plastids in the stomata is another way to determine the ploidy level.

Biochemical methods

Serological, electrophoretic, and chromatographic methods can also be used to distinguish between varieties. These methods are very time-consuming and expensive, however, and require considerable skill. In many species, thin-layer chromatography and electrophoresis have been used to distinguish between different varieties. Varieties do have specific isoenzyme patterns (Andersson, 1984).

Phenol: The phenol test is the one used most widely to distinguish between different wheat varieties. Biochemical studies on phenol color reactions show that it involves the enzyme tyrosinase using phenol as a substrate. It is an oxidation process in the surface layers of the seed.

Grains are soaked in distilled water for 24 hours; after the water is removed, 1% phenol is added. The ventral side of the grain should face downwards and the solution should not completely cover the grains. After 4 (and 24) hours the intensity of the color is evaluated, which is a varietal characteristic scored on a 0-9 scale. The lower glumes may also give specific coloration with phenol.

The test can also be used on dehulled oat seeds and on certain herbage seeds (ryegrass and *Poa pratensis*), but is less suitable for barley, which colors very erratically. Phenol has also been used to differentiate between chicory (*Cichorium intybus*) and endive (*C. endiva*), by treating embryos with a 0.5% solution.

Peroxidase: Some soybean varieties can be classified with the seed coat peroxidase test. Coats removed from the seed are treated with 0.1% hydrogen peroxidase solution (McDonald 1985).

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An Introduction to Seed Cleaning

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Introduction

Seed cleaning is one of the most effective ways to ensure good seed quality; done with the right equipment and appropriate methods, it can increase purity and germination; decrease the amount of other seeds and often also the number of diseased seeds; and improve the visual, commercial, and planting quality of the seed lot. Harvested seed must always be cleaned, for it inevitably contains empty, shrivelled, immature, and/or diseased seeds; bits of fruits, straw, chaff, and soil particles; and frequently seeds of weeds or other crops.

Well-equipped seed cleaning plants should be established in several localities in a country. Many manufacturers can install an entire seed cleaning plant as well as train staff to operate the machines; such "turn-key" projects are generally much more effective than those in which installment and training are done by local staff.

Seed Cleaning Machines and Working Principles

1. Air-screen cleaner

This is the most important machine, the "heart" of every cleaning plant. It uses screens and aspiration (air or "wind") for two separations.

The machine: Most air-screen cleaners consist of a shaking screen-case, a box that contains the screens or sieves, and one or more fixed air channels. The best separation occurs when the screen-case, or the two screen-cases, contain four or more screens (Fig. 1). The screens can be used as two sets of screens, to improve capacity; or as four independent screens (with holes of four different dimensions), to obtain maximum effect. Figure 2 shows three alternative ways to use four screens, employing two, three, or four different types of screens. The machines with two equal sets have the highest capacity, while four machines with four different screens are best for removing virtually all impurities.

The screens: These can be made of several types of materials, most commonly iron sheet. (Zinc or stainless steel are also available.) The sheet is perforated with round, oblong, or triangular holes (Fig. 3).

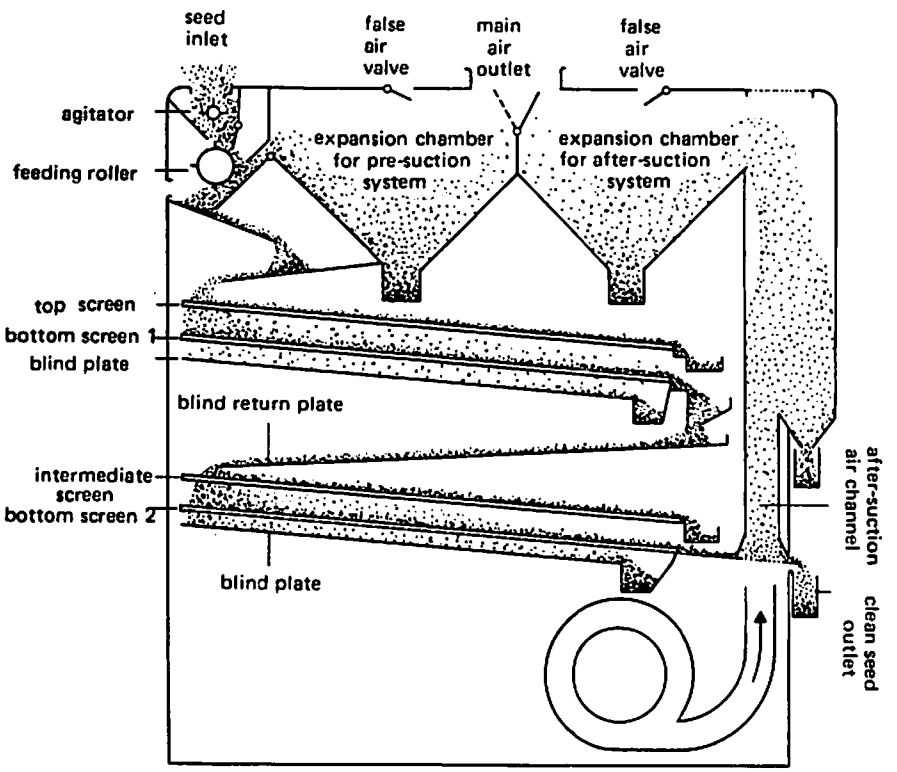


Fig. 1. Sophisticated air-screen cleaner, with pre- and post-suction and four screens (two bottom screens, one intermediate, and one top screen are used).

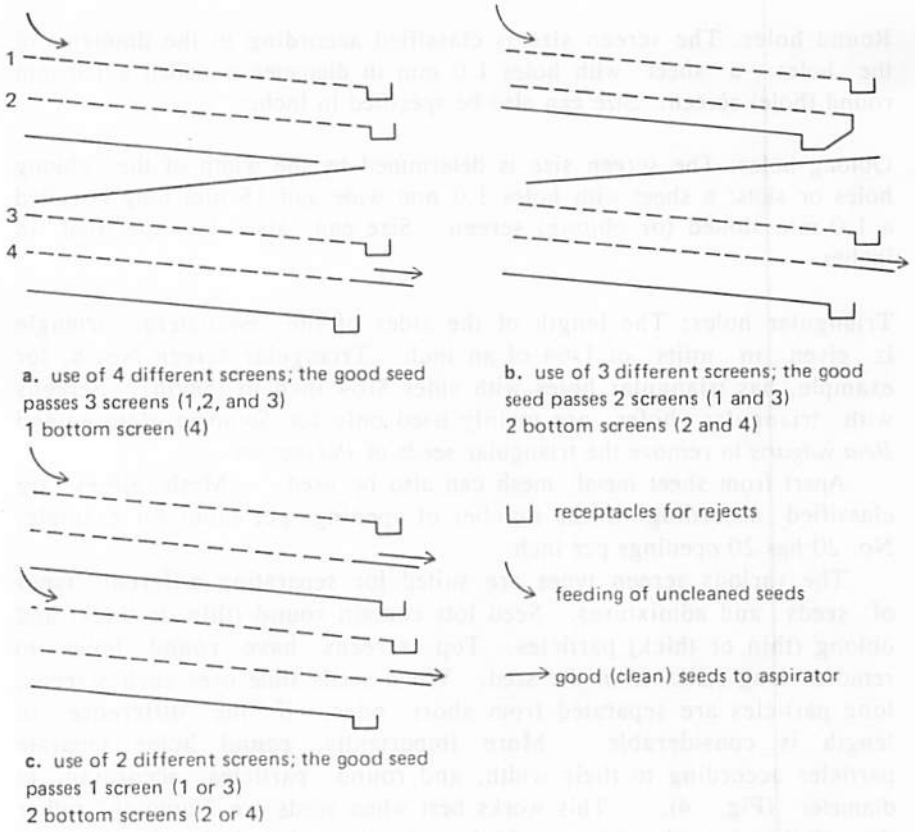


Fig. 2. Three ways to use a four-screen cleaning machine.

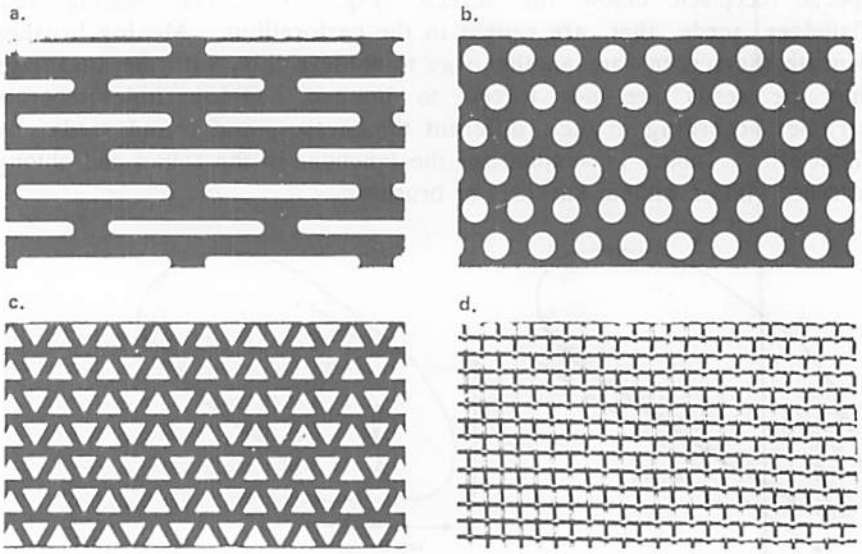


Fig. 3. Different kinds of perforations. a: slotted (oblong); b: round; c: triangular; d: mesh.

Round holes: The screen size is classified according to the diameter of the holes; a sheet with holes 1.0 mm in diameter is called a 1.0 mm round (hole) screen. Size can also be specified in inches.

Oblong holes: The screen size is determined by the width of the oblong holes or slots; a sheet with holes 1.0 mm wide and 15 mm long is called a 1.0 mm slotted (or oblong) screen. Size can also be specified in inches.

Triangular holes: The length of the sides of the equilateral triangle is given in units of 1/64 of an inch. Triangular screen No. 8, for example, has triangular holes with sides 8/64 inch in length. Screens with triangular holes are mainly used only for *Spinacia oleracea* and *Beta vulgaris* to remove the triangular seeds of *Polygonum*.

Apart from sheet metal, mesh can also be used. Mesh sieves are classified according to the number of openings per inch; for example, No. 20 has 20 openings per inch.

The various screen types are suited for separating different types of seeds and admixtures. Seed lots contain round (thin or thick) and oblong (thin or thick) particles. Top screens have round holes to remove long stalks from the seed. When seeds slide over such screens, long particles are separated from short ones, if the difference in length is considerable. More importantly, round holes separate particles according to their width, and round particles according to diameter (Fig. 4). This works best when seeds are "jumping" rather than sliding over the screen, which can be induced by beating the screen automatically with a beater (knocker), or with rubber balls in a special receptacle below the screen (Fig. 5). The beating also dislodges seeds that are caught in the perforations. Moving brushes beneath the screens are another way to achieve this, with the advantage that the seeds are not forced to bounce. Oblong holes separate particles according to their different thicknesses, and round seeds by diameter. Table 1 summarizes the functions of the round and oblong screens, with or without knockers or brushes.

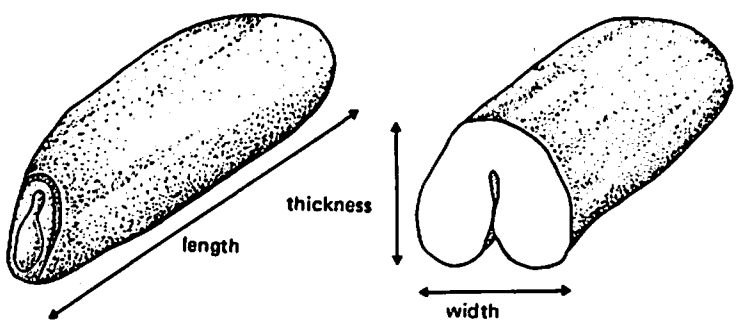


Fig. 4. Dimensions of a cereal grain.

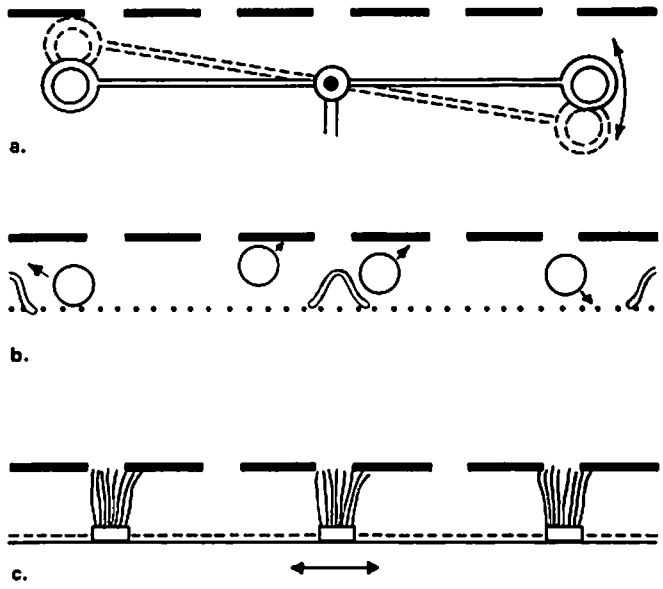


Fig. 5. Three possibilities for constant screen-cleaning. a: using a knocker (beater); b: with rubber balls; c: with brushes.

Table 1. Functions of round and oblong screens.

	Without knockers or balls (with or without brush cleaning)		With knockers or balls	
Particle shape	Round holes	Oblong holes	Round holes	Oblong holes
Short and thick	↓	→	↓	→
Long and thick	→	→	↓	→
Short and thin	↓	↓	↓	↓
Long and thin	→	↓	↓	↓

↓ = pass through screen
→ = remain on screen
Note: The functioning of oblong screens is not affected by knockers or balls. On a round screen with knockers, only particles that are wider than the hole are retained (not shown in the diagram).

Mesh sieves are not often used for agricultural crops, because the holes of a given screen usually differ in size. Their advantage, however, is that they have a large total area of openings, or effective screen area, with up to ± 50% of the area consisting of openings, a percentage much lower in round, oblong, and triangular screens, depending on the hole arrangements. Nevertheless, mesh sieves are used for small seeds such as those of flowers. (Table 2 gives more detail about screen sizes.)

The aspirator: Air-screen cleaners have a built-in aspirator which can separate light impurities such as empty or partly-filled seeds, husks, and glumes from the seed. Larger machines have a double aspirator (Fig. 1): a pre-suction channel takes up light impurities before the seed reaches the screens, and an after-suction or blowing system removes impurities that remain after the seed has passed the screens. The pre-suction should not be adjusted too strongly; only impurities other than seed should be removed. The pre-suction is meant to reduce volume, thus making the screens more effective. The after-suction must be set very carefully to remove empty or low quality seeds, not straw and stalk pieces, which should be removed with the screens. If straw and stalk pieces still remain, the round hole screen should be replaced with one of a smaller size, or an oblong screen replaced with a round one.

There are also aspirators that are not combined with screens. These are often used as pre-cleaners for heavy-seeded crops such as peas and beans that contain large amounts of light trash. After the seed passes through the aspirator, it is fed into the air-screen cleaner.

2. Indented cylinder

While the screens of the air-screen cleaner separate seed mainly according to width and thickness, the indented cylinder (or indented disk) (Figs. 6 and 7) separates according to length. Because there are always impurities (especially broken seeds and weed seeds) that are either longer or shorter than the crop seed, this machine is nearly always needed.

Two ways to use the indented cylinder: The indentations, also called cells or pockets, lift particles up to a certain height. At that point, the particles drop out of the cell and fall downwards. The cylinders revolve at a certain fixed speed, so particles of a

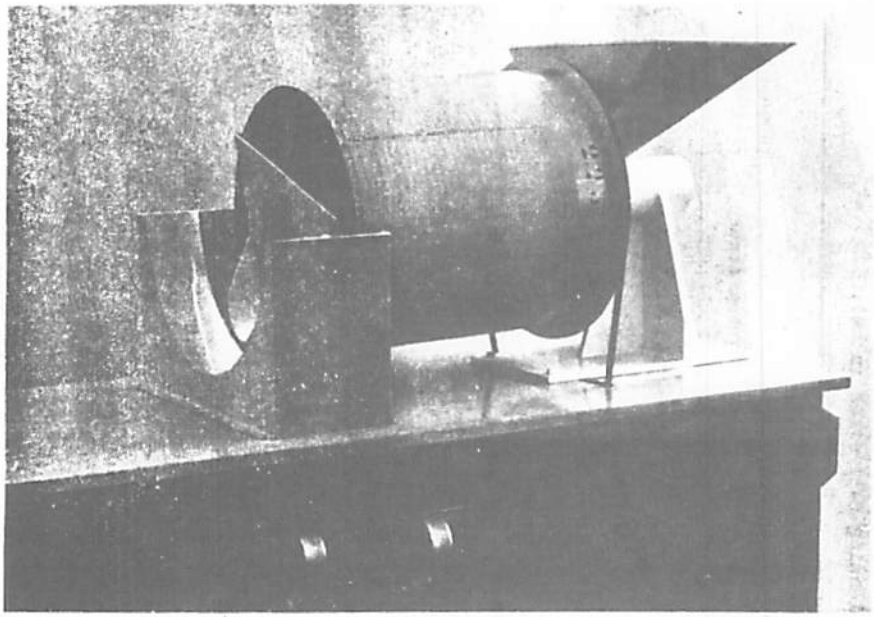


Fig. 6. Indented cylinder, laboratory model; the adjustable trough is clearly visible.

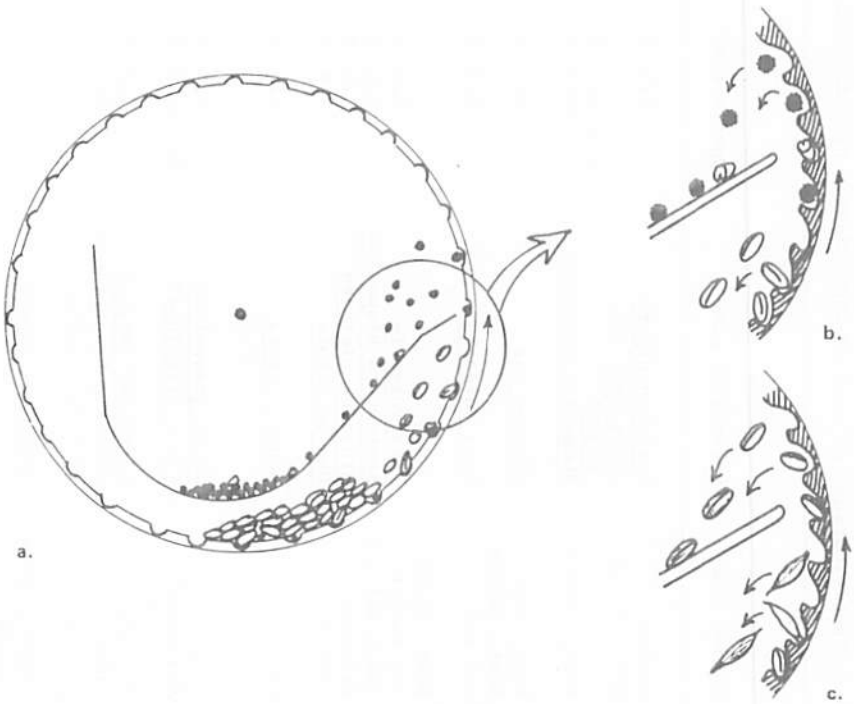


Fig. 7. a: working principle of indented cylinder; b: round-grain application; c: long-grain application.

Table 2. Specifications of screens and indented cylinders used in cleaning (all sizes in mm).

No.	Common name	Scientific name	Upper screen	Intermediate screen (upper)	Intermediate screen (lower)	Bottom screen	Indented cylinder
1	Barley	Hordeum vulgare	6.5 R	4.5 S	4.0 S	2.1 -2.4 S	5.5 -6.5
2	Bean, broad	Vicia faba var. major*	10.0-12.0 R	-	-	5.5 -6.0 S	-
3	Bean, common	Phaseolus vulgaris	10.0 R	-	-	3.75-4.5 S and 4.25-5.5 R	-
4	Bean, soya	Glycine max	9.0 R	-	-	3.0 -4.0 S	-
5	Beet, garden and red	Beta vulgaris	9.0 R	8.5 R	7.6 R	2.0 -3.0 R	-
6	Beet, sugar and fodder	Beta vulgaris	8.0 R	-	-	3.2 R	-
7	Black salsify	Scorzonera hispanica	7.0 R	2.7 S	2.6 S	1.0 S	4.5
8	Cabbages	Brassica oleracea	2.7- 3.4 R	2.5-3.2 R	2.3-3.0 R	0.9 -1.1 S	-
9	Carrot	Daucus carota	4.9 R	4.1 R	2.2 S	1.3 R	1.75-2.5 and 4.5 -6.5
10	Carrot	Daucus carota	2.8 R	2.5 R	1.3 S	1.0 R	1.5 -2.5 and 3.5 -5.5
11	Celery	Apium graveolens	1.8 R	1.6 R	1.5 S	0.4 R	1.5 -2.5
12	Chickpea	Cicer arietinum*	8.0-11.0 R	-	-	4.0 -5.0 S and 5.0 -5.5 R	-
13	Chicory	Cichorium intybus	2.8 R	1.8 S	1.5 S	0.7 S	2.5-3.25
14	Chives	Allium schoenoprasum	3.2 R	2.5 R	2.4 R	1.2 S	-
15	Clover, red	Trifolium pratense	2.5 R	2.4 R	1.5 S	1.0 -1.2 R	2.5
16	Clover, white	Trifolium repens	1.5 R	1.4 R	0.9 S	0.8 R	-
17	Cowpea; stringbean	Vigna unguiculata*	6.0- 8.0 R	-	-	3.0 -3.3 S	-

18	Flax; linseed	Linum usitatissimum	5.0	R	1.7	S	1.4	S	1.8 -2.0	R	3.5
19	Gram, black	Phaseolus mungo	6.0	R	-		-		3.0 -3.2	S	-
20	Gram, green	Phaseolus radiatus	5.0	R	-		-		2.8 -3.2	S	-
21	Leek	Allium porrum	3.8	R	2.8	R	2.7	R	1.5	R	-
22	Lentil (large)	Lens esculenta	8.0	R	-		-		5.5 -6.5	R	-
23	Lentil (small)	Lens esculenta	5.0	R	-		-		3.0 -3.5	R	-
24	Lupin, yellow	Lupinus luteus	6.25	R	6.0	R	5.0	R	3.0	S	-
25	Maize; corn	Zea mays *	-		-		-		2.5	S	5.5-8.0
26	Melon	Cucumis melo	5.0	S	3.5	S	3.0	S	3.5	R	-
27	Oat	Avena sativa	7.5	R	3.2	S	3.1	S	1.8 -2.2	S	7.0-8.0
28	Onion	Allium cepa	4.0	R	3.0	R	2.9	R	1.8	R	-
29	Parsley	Petroselinum crispum	2.8	R	2.2	R	1.6	S	0.6 -0.75	R	2.0-3.0
30	Pea	Pisum sativum	9.0-10.0	R	-		-		3.75-4.5	S and	-
									4.25-6.5	S	
31	Poppy	Papaver somniferum	1.5	R	1.4	R	1.3	R	0.3	S	-
32	Radish	Raphanus sativus	5.0	R	4.5	R	3.8	R	1.3 -1.4	S	4.5-5.5
33	Rape	Brassica napus	3.4	R	3.2	R	3.0	R	0.9 -1.1	S	-
34	Rapeseed	Brassica napus	3.2	R	2.8	R	2.3	R	0.9 -1.0	S	-
35	Rice; paddy	Oryza sativa	6.0- 7.5	R	-		-		1.8 -2.1	S	5.5
36	Rye	Secale cereale	6.25	R	3.3	S	3.2	S	1.8 -2.0	S	5.0-6.0
37	Spinach (prickly seed)	Spinacea oleracea	9.0	R	8.5	R	7.6	R	2.7 -2.8	R	8.0
38	Spinach (round seed)	Spinacea oleracea	4.9	R	4.8	R	4.5	R	2.3 -2.4	R	4.5-5.5
			8.0	S	7.5	S	6.5	S	6.0	R	-
39	Squash	Cucumis pepo									
40	Tomato	Lycopersicon lycopersicum	4.7	R	4.5	R	4.0	R	1.8 -2.2	R	6.5
41	Turnip	Brassica rapa	3.2	R	2.8	R	2.3	R	0.9	S	-
42	Wheat	Triticum aestivum	6.25	R	4.5	S	4.25	S	2.0 -2.5	S	5.5-7.0

R = round holes; S = slotted (oblong) holes.
*Great differences between the varieties makes it nearly impossible to indicate proper screen sizes.

particular size will always drop out of the cells at a certain height in the same cylinder. Longer particles will drop out earlier or lower, and when a tray is placed between these points, a separation occurs. One can make use of the machine in two different ways. In the round-grain application, shorter impurities are lifted and longer crop seeds left below. In the long-grain application, crop seed is lifted and longer impurities left below.

Of course, the cell sizes should be larger for the long-grain application, when the crop is the same for both applications. Also, there is a higher risk of losing good seed with the long-grain application; if the crop seeds are not lifted, they are discharged together with the long impurities, so less volume per time unit can be cleaned with the long-grain. To keep up with the capacity of the material passing through the air-screen cleaner and the round-grain, two long-grain cylinders are required. Fig. 8 shows the flow of seeds over this combination of machines.

For many crops, the air-screen cleaner combined with the cylinder produces a clean seed lot. These two machines separate seed according to all its important characteristics: width, thickness, length, and specific gravity (air separation).

In some cases, especially when standards are very high, additional machines are needed that use seed characteristics more extensively (e.g., long screen machine, vibratory screeners, cylinder screen machines, and specific gravity separators). These specialized machines are economical only in certain cases.

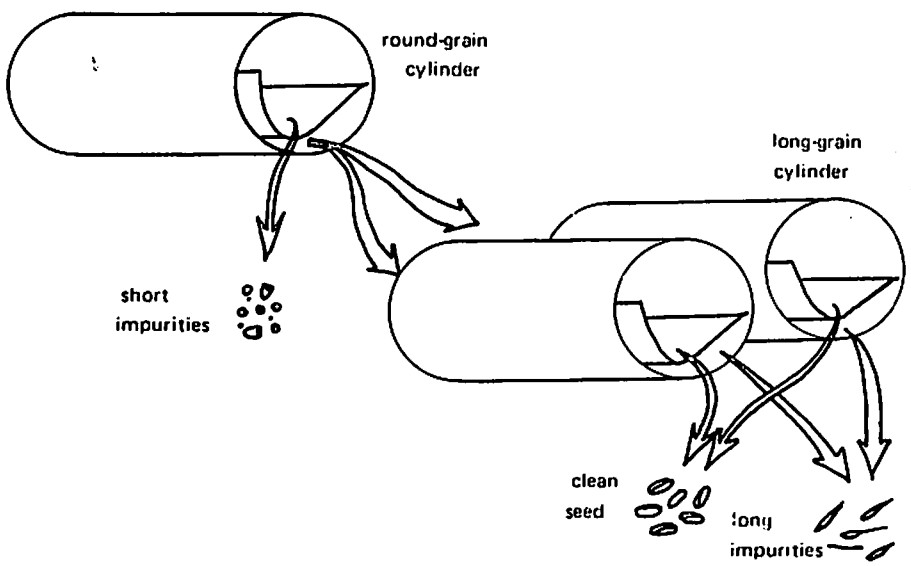


Fig. 8. The flow of seeds over the standard arrangement of one round-grain and two long-grain cylinders.

3. Specific gravity separator

Even after the seed is completely clean, it may be necessary to obtain higher quality seed, if germination capacity is not yet above minimum, or if a very high germination capacity is required. Some impurities may also remain, such as particles of exactly equal dimensions, which are impossible to remove with the normal set of cleaning machines. In such cases the seed can be passed over the specific gravity separator, a machine whose operation requires care and experience. The seed that falls into the higher density classes is generally better quality. (Soil clods with a much higher density than the seed can be removed separately.)

Seeds are fed onto the specific gravity separator in a layer three-to-five seeds thick (Figs. 9 and 10). The shaking deck pushes the seeds uphill (from left to right in the figures), but because air flows evenly through the deck, only the heavier seeds touch the deck and are pushed uphill, while the lighter seeds more or less float downhill over the heavy ones. Several outlets can be combined if needed to collect clean seed and waste material separately. Seed can also be separated into different classes.

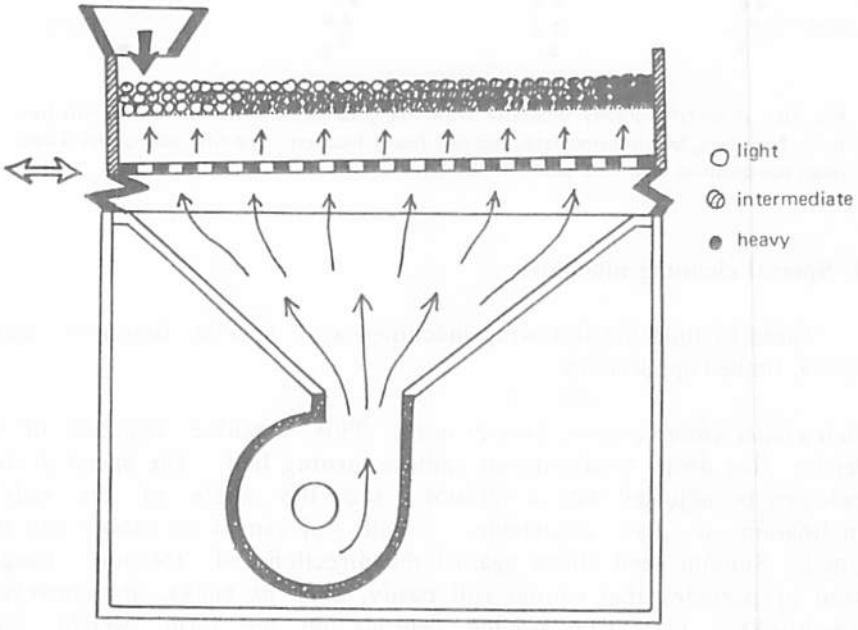


Fig. 9. Working principle of the specific gravity separator.

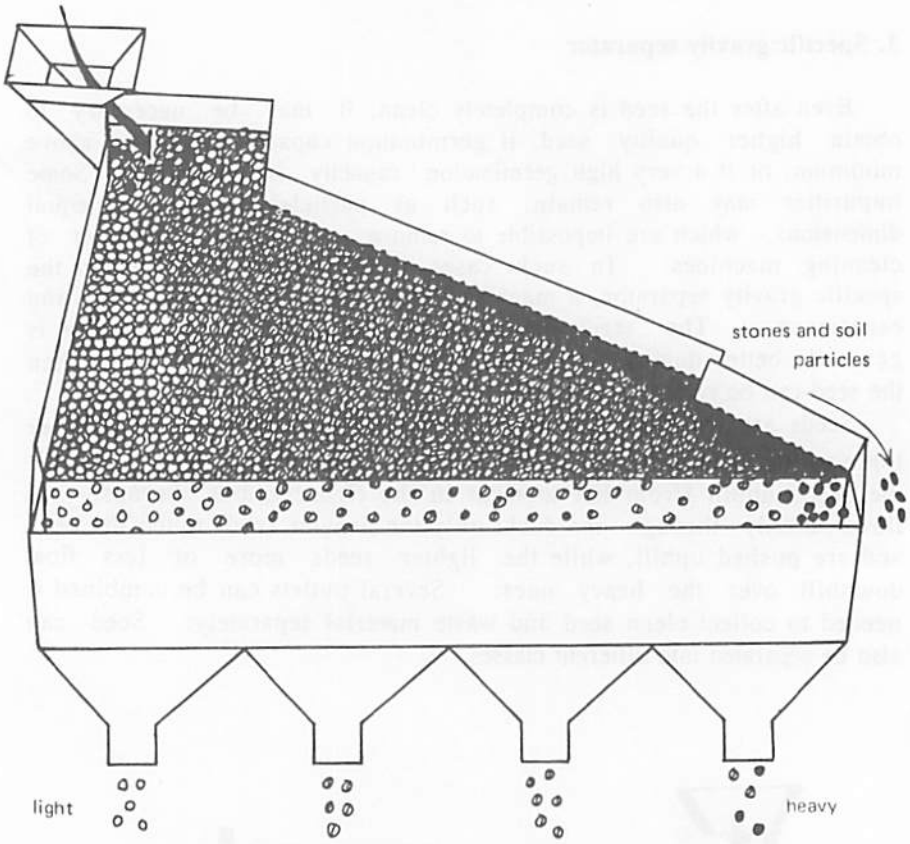


Fig. 10. A specific gravity separator with triangular deck showing the different fractions: one light, two intermediate, and one heavy fraction. The fifth side outlet is used when soil particles (e.g., clay clods) are present.

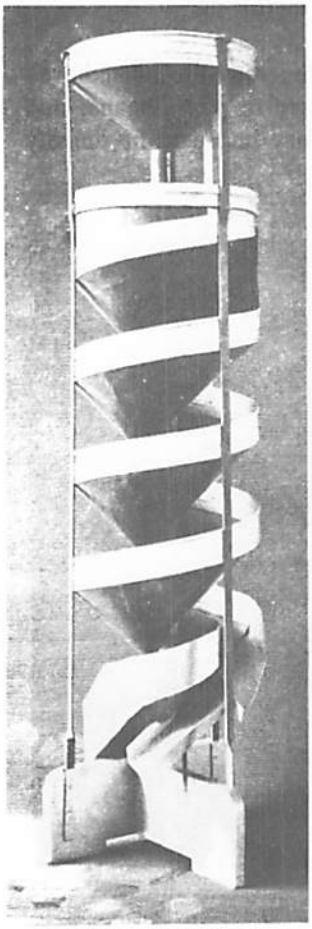
4. Special cleaning machines

These include the following machines with special functions and, hence, limited applications.

Belt grader (*Band grader*, *Draper mill*): This machine consists of a feeder that drops seed onto an endless turning belt. The speed of the belt can be adjusted with a variator, and the angle of the belt's inclination is also adjustable. Belts of canvas or rubber can be fitted. Smooth seed slides against the direction of rotation; rough seed or particles that cannot roll easily, such as stalks, are conveyed upwards (Fig. 11). The grading depends on the form, weight, and surface structure of the seed, and on the inclination, speed, and material of the belt. The seed species, and the extraneous matter to

be separated, determine whether a canvas or rubber belt is used. The belt grader is especially suitable for separating stalks from beet seed and for cleaning flower seed.

Spiral separator: The spiral separator, which classifies seed according to its shape and rolling ability, consists of sheet metal strips fitted around a central axis in the form of a spiral (Fig. 12). The unit resembles an open screw conveyor standing in a vertical position. The seed is introduced at the top of the inner spiral. Round seeds roll faster down the incline than flat or irregularly-shaped seeds, which tend to slide or tumble. The orbit of round seed increases with speed on its flight around the axis, until it rolls over the edge of the inner flight into the outer flight where it is collected separately. The slower-moving seed does not build up enough speed to escape from the inner flight. Most spirals have multiple inner flights arranged one above the other to increase the capacity.



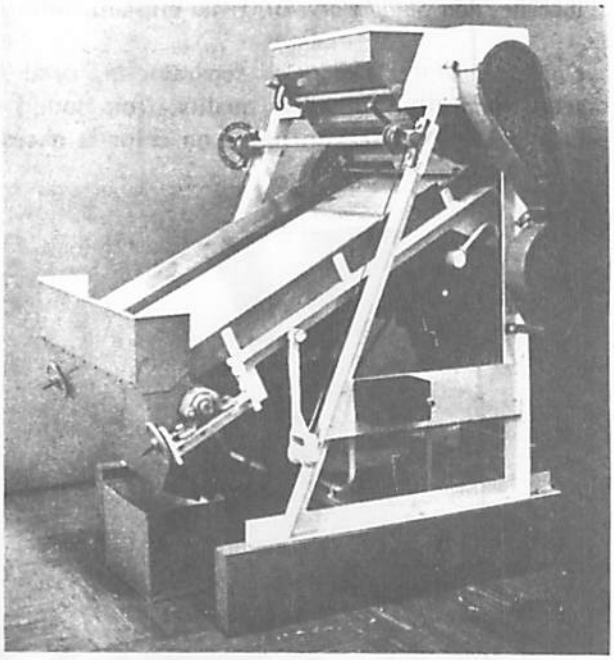


Fig. 11. Belt grader.

Fig. 12. Spiral separator.

The spiral separator is used for damaged seed from *Brassica* spp., peas, and soybeans, and for separating *Galium* (cleavers) from spinach.

Magnetic separator (Magnetic drum): The magnetic separator separates seed according to its surface texture or related seed characteristics. First, seed is treated with iron filings, which adhere to rough seed only. The treated seed lot is passed over a revolving magnetic drum; the particles coated with iron filings are attracted to the drum and separated from smooth, uncoated seed (Fig. 13).

It may help to add varied amounts of water while mixing seed and powder, depending on the seed type. At any rate, the effectiveness of magnetic separation depends on the components of the seed lot, and on the powder and water used in the treating operation. The greater the difference between surface textures of the seed lot's components, the more effectively they can be separated.

The machine is useful for separating *Stellaria media* (chickweed) from clovers and lucerne (alfalfa), *Cuscuta* (dodder) from clovers and lucerne, and *Sinapis arvensis* (wild mustard) from *Brassica* spp.

Color separator: The color separator is used to separate discolored seed, generally of lower quality, from sound seed of peas, beans, and faba beans. Separation based on color is necessary because the density

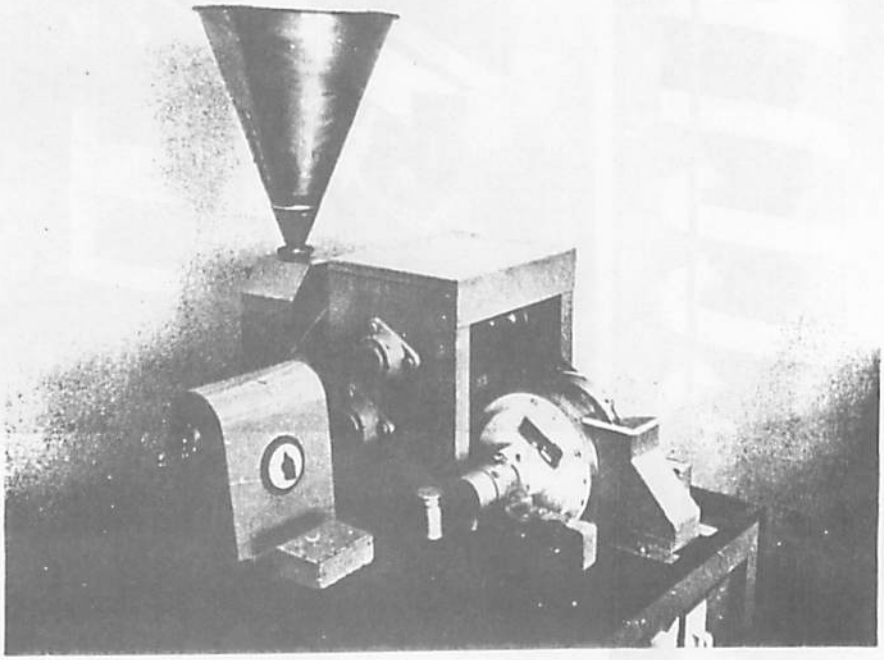


Fig. 13. Magnetic separator, laboratory model.

and dimensions of discolored seed are the same as those of sound seed, so other machines are not effective for separation. Electronic color separation uses photo cells to compare the seed color with "background plates," which are selected to reflect the same light as the good seed. Seed that differs in color is detected by the photo cells, which generate an electric impulse. The impulse activates an air jet to blow away the discolored seed.

Paddy table: Paddy (rice in glumes) can be cleaned from naked cariopses with this machine, which operates on the specific gravity and surface texture of the seeds, combined with resilience. Successful applications are also possible in linseed, wheat, and barley. The machine is often now replaced by specific gravity separators; the paddy table, however, retains more good seed, and is easier to operate in continuous processes.

The Structure of a Cereal Seed Cleaning Plant

In addition to an office and a small quality laboratory, the plant should have the following facilities (see simplified diagram, Fig. 14).

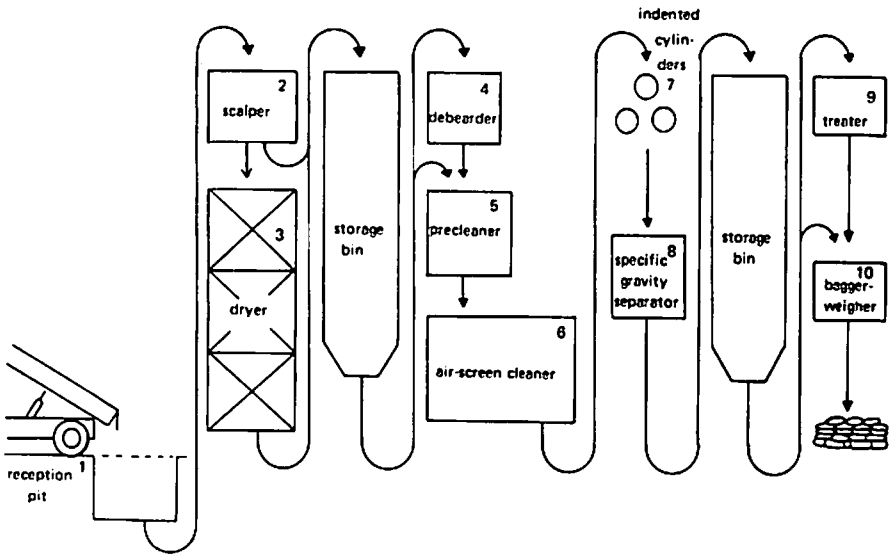


Fig. 14. Simplified diagram of a cereal seed cleaning plant (small buffer bins not shown).

Reception: The crude material is delivered in bags or bulk to the reception area. Bags must be opened or placed on a dryer for bagged seeds.

Scalper: It is more economical to remove the largest trash before the raw material is dried. A simple screen machine with large perforations in the screens removes only particles much larger than the seeds.

Dryer: If the moisture content requires it, seed is dried in this machine.

Debearder (Brushing machine. De-awner): The seed is kept in a storage bin until it can be run through a debearder or brushing machine, which completes what the thresher has left undone. The brushing machine is not always needed, but is useful to separate oat seeds from one another, to remove awns from barley, and to separate rye and wheat from their husks.

Pre-cleaner: If a scalper is not used, a pre-cleaner may be necessary to remove large impurities and reduce the volume. It also feeds material evenly into the air-screen cleaner.

Air-screen cleaner: This machine and the indented cylinder separator form the heart of the seed cleaning plant, where the basic or fine cleaning is done. This machine both separates larger and smaller impurities, using screen perforations of carefully-chosen sizes; and carries out one or more air-separations to remove the light impurities and empty or shrivelled seed.

Indented cylinder separator (or disc separator): This machine is also essential; it separates shorter and/or longer impurities (shorter seeds of other species, broken seeds, soil particles, or stalks).

Specific gravity separator: This machine, used in many plants, does specific gravity grading which the air has left undone. It is able to separate according to smaller differences in specific gravity than the air-screen cleaner, so that germination capacity can be improved by removing inferior grains; ergot-affected seeds can be partly eliminated; and the number of soil particles can be further reduced.

Treater (Dresser): The seed is then stored in a silo to await treatment, bagging, and dispatch. If the seed needs fungicide and/or insecticide treatment, it is passed through a seed treater.

Bagger-weigher: After treatment, the seed can be bagged with an automatic weighing and bagging unit.

Internal transport: Vertical conveying is usually done by bucket elevators, while horizontal transport is done mostly with belt conveyors. Pneumatic transport is not recommended for sowing seed plants. Seed is fed into most of the machines from buffer bins for two reasons: to assure a constant flow of seed at the same rate throughout the plant, and to avoid overloading certain machines, especially the air-screen cleaner, indented cylinders, treater, and bagging unit which do not operate properly with excess seed.

Notes to Table 2

Nos. 1, 25, 27, 35, 36, 42; Cereals including rice and maize. The bottom sieve and air speed must be selected according to the variety. The indented cylinder is important to remove broken grains and weed seeds from barley, oats, and wheat. The specific gravity separator can be used to eliminate stones and clay clods, pre-germinated seeds, and cereal admixtures (e.g., wheat from barley). The indicated bottom sieve in maize removes broken kernels; a large round (10.0-12.0 mm) top screen can be used if parts of the cobs must be removed.

No. 2; Broad bean (faba bean). Broken seeds can be partially removed with a carefully-chosen bottom screen. Hand picking is essential for this crop (see below under "Bean").

Nos. 12, 30; Chickpea and pea. Two bottom screens are necessary if the lot contains broken seeds. A slotted screen separates the seeds from the halves and smaller pieces, while a round screen is fitted to remove immature undersized seeds. A typical arrangement of screens is shown in Fig. 2b; if this is not used, the seed lot must pass through the machine twice, once with the slotted bottom screen fitted and again with the round bottom screen. It is necessary to fit a knocker or balls below this sieve.

Nos. 3, 4, 17; Bean, soybean, cowpea. The instructions for broken and undersized seeds of peas apply here as well. Broken seeds of soybean can also be removed with a spiral separator. Discolored diseased seeds and seeds damaged by the harvester/thresher can be removed either with a color separator or by hand along a picking-belt, which moves the seeds in a continuous stream past workers who remove the bad seeds.

Nos. 19, 20; Grams. Insect-damaged seeds can be removed partly by air and partly with a needle cylinder--an indented cylinder provided with

thousands of needles parallel to the inner surface, pointing in the direction of rotation, that lift those seeds with holes. Undersized and shrivelled seeds need special treatment and can be removed with the proper bottom screen.

Nos. 22, 23, 24; Lentils and lupins. These seeds are difficult to clean, especially lentils because they are flat. It is necessary to knock the screen to force the seeds to "jump", otherwise they block all the screen holes. Small weed seeds can be removed with the indented cylinder. The spiral separator can be used for round-seeded weeds. Depending on the seed lot, a top screen with oblong perforations is often used.

Nos. 5, 6; Beets. Stem parts are removed on a belt grader for pre-cleaning (stems are transported upwards, seeds roll down). Soil clods and large seeds of other species (pulses, cereals) are removed with the air-screen cleaner using "reversed blowing" : extra high air speed blows up good seed and leaves the impurities. *Polygonum* seeds are removed with triangular screen No. 11.

Nos. 8, 32, 33, 34, 41; Cruciferae (cabbages, rapeseed, radish, etc.). Clay particles can be removed with the spiral separator. The bottom screen, if knocked, can separate the broken, halved seeds. Charlock (wild mustard, *Sinapis arvensis*) can be removed with the magnetic separator. Pre-germinated and insect-damaged seed can be removed with an increased air speed, but some good seed will be lost as well.

Nos. 9, 10, 11, 39; Umbelliferae (carrot, parsley, celery). Carrot seeds must be brushed to remove most or all "hairs" before the actual cleaning. The seed should not be stripped completely naked, however, because the embryo might be damaged. Indented cylinder 1.75-2.5 mm is used to remove small weed seeds. Cylinders 3.5-5.5 mm are used to lift the seed and leave stem pieces and flower stalks (in the long grain application).

Nos. 14, 21, 28; Onion, leek, chives. The gravity separator is used to remove the light-colored parts of fruits and inflorescences.

Nos. 15, 16; Clovers. Rough weed seeds can be removed with velvet rolls or a magnetic separator. Splitting the seed lot with a 0.7 mm slotted screen can often solve the weed problem: both lots are treated differently, using round screens, ventilation, or an indented cylinder, depending on the type of weed seeds present. The good seed from both lots is later mixed again. The specific gravity separator is useful for removing grasses and clay clods.

No. 40; Tomato. Seeds that adhere to one another can be separated with a slotted screen of 1.7, 1.8, or 1.9 mm, depending on the seed variety, and by subsequent rubbing between the hands. Extraction from fleshy fruits can be done with a pulper, after which the seeds are usually fermented. The liquid temperature should preferably not exceed 25°C (maximum 30°C), with the bin placed in the shade outside the building for no more than two days to avoid damaging the seed. Drying temperature after washing should also not exceed 30°C (maximum 35°C).

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An Introduction to Moisture Determination of Seeds

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Moisture Determination of Seeds

The moisture content of seeds is an important determinant of the duration of seed viability. High moisture content at harvest can increase the seeds' susceptibility to threshing damage. Later, during storage, a high moisture content decreases viability more rapidly because of mold growth, heating damage, ageing, and greater insect damage. It is important, therefore, to know the seed's moisture content immediately after harvest and, when necessary, after artificial drying as well.

The seed trade allows a certain moisture percentage depending upon the seed type. The objective of moisture analysis is to determine the moisture content of a seed lot at sampling. Therefore, the sample must be handled in such a way as to conserve its initial moisture content: it should be packed in a moisture-proof container (metal or plastic), submitted to the seed testing station without delay, and analyzed immediately upon arrival. During the determination, the seed should be exposed to the laboratory atmosphere as little as possible. For species that do not require grinding, the sample must be transferred from its original container to the drying container within two minutes or less. (Fig. 1 illustrates some equipment used to test moisture.)

Moisture Determination Methods

Air-oven method: This is the common standard method, which removes water from the seed by drying under prescribed and controlled

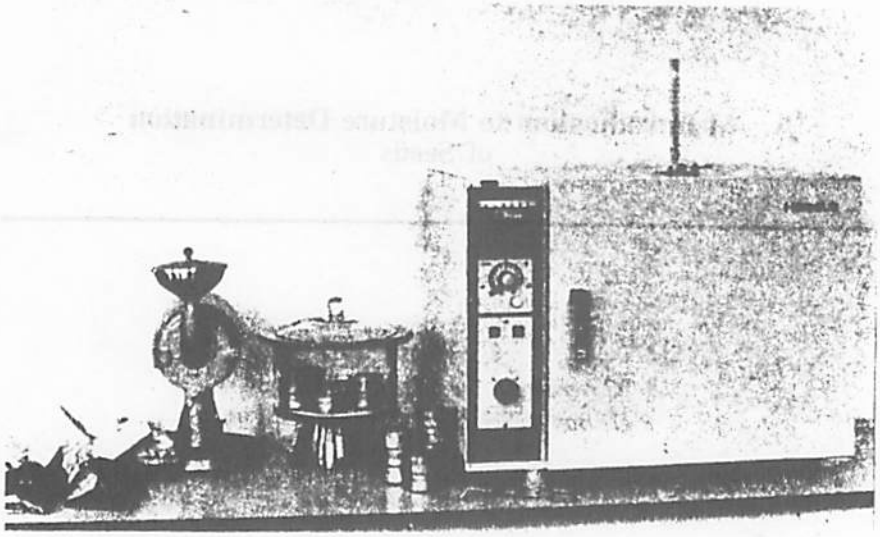

Fig. 1. Moisture testing equipment.

conditions. For detailed specifications, see International Seed Testing Association Rules, Chapter 9 (ISTA 1976).

Equipment

- Containers of non-corrosive metal approximately 0.5 mm thick, with sides rounded at the base, a flat bottom, level edges, and a loose-fitting cover. The container should be 3 cm high with a base diameter of 6 cm. The effective surface of the bottom must be large enough to distribute the working sample in a layer of not more than 0.3 g/m^2 (= $\pm$ 17 cm^2 for the usual 5 g). Both the container and its cover should be labelled with the same number so that each sample can be identified during the test.
- An electrical oven with adequate ventilation and a thermostatic or electronic control for constant temperature.
- A balance that weighs accurately in grams to three decimal places (precision of 1 mg).
- A grinding mill constructed of material that cannot absorb moisture. (Wood is not suitable.) The mill's construction should protect the seeds and the resulting ground material as much as possible from exposure to the room's atmosphere during grinding. The mill should grind evenly, and not be run at a speed high enough to heat the ground material. Air currents that accelerate the evaporation of moisture must be reduced to a minimum. The mill should be able to be adjusted to different degrees of grinding fineness, and allow thorough cleaning.

- Two mesh sieves with receptacle and lid. The mesh openings should be 0.5 and 1.0 mm wide.
- A desiccator with a suitable desiccant such as silica gel. The desiccator should have a thick metal or porcelain plate to accelerate cooling of the containers and seed. The desiccator's bottom compartment contains the silica gel, preferably colored with cobalt chloride as an indicator. As soon as the dark blue color turns pale pink, the desiccant should be reactivated by heating at 130°C in the oven.
- A brush and a steel brush to clean the mill after grinding.
- Several metal trays with holes about 5 mm in diameter. Seed containers placed on the trays can be moved easily into and out of the oven; the tray holes promote air circulation in the oven.
- A pair of crucible tongs and a cloth to remove hot containers in the trays from the oven.
- A small spoon to transfer the seeds into the container.

Procedure

Moisture analyses are carried out on independently-drawn duplicate working samples, weighed to an accuracy of 1 mg. Most species are dried for one hour at 130°C, except for cereals (two hours) and maize (four hours). Also, seeds containing oil are dried for 17 hours at 103°C. (For detailed specifications, see ISTA Rules, Chapter 9; and Table 1 of this paper.)

Each empty container is weighed with its cover. The submitted sample is mixed thoroughly with a small spoon, and two portions of 5.0 g each are weighed along with the containers. The seed should be distributed evenly over the bottom of the container. After weighing, the containers are placed on top of their covers on the tray in the pre-heated oven (heated to the prescribed drying temperature, Table 1). After drying, the containers are closed with their covers (using tongs and a cloth), allowed to cool for 30 minutes in a desiccator, and weighed again. The moisture content (M) is calculated to one decimal place using the formula:

$$M = \frac{M2 - M3}{M2 - M1} \times 100 = \frac{\text{loss of weight}}{\text{initial weight of seed}} \times 100$$

M1 = weight of empty container with cover
M2 = weight of container with cover and seeds before drying
M3 = weight of container with cover and seeds after drying.

The results of the duplicate determinations should not differ by more than 0.2%; otherwise, the analysis should be repeated in duplicate.

Table 1. Specifications for moisture test of different species, using the air-oven method.

Scientific name	Common name	Grinding*	Drying time (hours)	Drying temperature (°C)	Moisture content % above which pre-drying is done (if necessary)
Allium spp.	onion, leek	-	17	103	-
Arachis hypogaea	groundnut	C	17	103	17.0
Avena sativa	oats	F	2	130	17.0
Brassica spp.	cabbage	-	17	103	-
Cicer arietinum	chickpea	C	1	130	17.0
Daucus carota	carrot	-	1	130	-
Glycine max	soya bean	C	17	103	10.0
Gossypium spp.	cotton	F	17	103	17.0
Hordeum vulgare	barley	F	2	130	17.0
Lens culinaris	lentil	C	1	130	17.0
Lycopersicon lycopersicum	tomato	-	1	130	-
Medicago spp.	medic	-	1	130	-
Oryza sativa	rice	F	2	130	13.0
Pennisetum glaucum	pearl millet	F	1	130	17.0
Phaseolus spp.	bean	C	1	130	17.0
Pisum sativum	pea	C	1	130	17.0
Secale cereale	rye	F	2	130	17.0
Sorghum spp.	sorghum	F	1	130	17.0
Trifolium spp.	trefoil	-	1	130	-
Triticosecale spp.	triticale	F	2	130	17.0
Triticum spp.	wheat	F	2	130	17.0
Vicia spp.	vetch	C	1	130	17.0
Vigna spp.	cowpea, stringbean	C	1	130	17.0
Zea mays	maize	F	4	130	17.0

*F= fine grinding; C = course grinding; - = no grinding necessary.

Grinding and pre-drying

Some seed species must be ground before the actual moisture content is determined (e.g., cotton, rice, maize, cereals, peas, and beans). Cereal and cotton seeds must be finely ground; at least 50% of the ground material must be able to pass through a wire sieve of 0.5 mm mesh size, and not more than 10% should remain on a sieve with 1.0 mm meshes. For leguminous seeds, only coarse grinding is necessary; at least 30% of the ground material should pass through a wire sieve with 1.0 mm meshes. The grinding mill should be adjusted to produce particles of the required dimensions, and a quantity of the sample larger than that required for the test (about 20 g) should be ground. Seeds of *Vicia faba* might be difficult to grind because of their size; they can be cut into small pieces before grinding.

If the seed sample requires grinding and the moisture content exceeds 17% (or 10% in soybeans and 13% in rice), pre-drying is necessary before grinding. For this, two 50 g samples are weighed and placed on two open trays at 130°C for 5 to 10 minutes. Very moist seed, about 25% moisture content or greater, is spread on two open trays and dried at 70°C for two-to-five hours, depending on the initial water content. The trays are then left uncovered in the laboratory for at least two hours. If the laboratory room's relative humidity exceeds 70%, it is preferable to put the pre-dried seeds in a closed desiccator. The two samples are then weighed separately and a portion is ground (e.g., 20 g).

The ground material is then subjected to a moisture test using the air-oven method. The moisture content (M) is calculated according to the following formula:

$$M = S_1 + S_2 - \frac{S_1 \times S_2}{100}$$

S_1 = percentage of moisture lost by pre-drying (stage 1)
S_2 = percentage of moisture lost by the oven method (stage 2)

The reported moisture content of the pre-dried sample is the averaged result of the pre-dried duplicate determination, rounded off to the nearest 0.1%.

Quick methods

A variety of brands and types of equipment are available to shorten the time needed for moisture determination. The quick-test methods should be calibrated or checked against the standard air-oven method. Because of the uncertainties associated with using most quick methods, ISTA has designated the air-oven method as the only official method.

The types of equipment for the various quick methods operate on different principles. Equipment includes:

- An apparatus that weighs seed on a built-in balance; seed is heated directly with an infrared lamp or electric heating elements.
- Electric moisture meters, which determine seed moisture by its conductivity.
- Electronic humidity-measuring instruments, which measure the relative humidity of the air around the seed. (The RH is in equilibrium with a certain or absolute moisture content of the seed.)

Using the first or direct heating method, the material must be heated to a temperature higher than that required for the air-oven method. Most of these apparatus have a balance which continuously measures the weight loss of the sample during heating. The moisture

percentage is usually read from a direct reading scale, and calculations are required. The test can be finished in 10-15 minutes, depending on the kind of seed under analysis.

Electric moisture meters are also frequently used for a quick test, because they are faster than any other method, and the test can be completed in one minute. Such meters measure either conductivity or dielectric properties of seeds.

For accuracy, meters used for the quick methods must be calibrated for each species against the standard air-oven method. The moisture determination should be executed under standardized conditions. In general, however, the results from the meters are less accurate than those from the air-oven method, because the meters cannot be read very precisely. Consequently, calibrated meters are only suitable for approximate determinations of moisture content.

In order to use the relative humidity instruments, it is important to understand the relationship between relative humidity and seed moisture content. (The following explanation was derived from Justice and Bass, 1978.) The moisture percentages of seeds in equilibrium with a specific relative humidity vary with crop species. At any temperature, air will hold a given amount of water in the form of vapor; air that contains all the moisture it can is called "saturated", a state equivalent to the dewpoint or 100% relative humidity. Warm air can hold more water than cool air. If the amount of water in the air is lowered, the relative humidity will be decreased. Data from Hubbard *et al.* (1957) (quoted by Roberts 1972) show that a decrease in temperature from 35 to 25°C increases the moisture content of wheat by almost 1% at 75% relative humidity.

Under all storage conditions the moisture content of seed will reach equilibrium with the surrounding air if enough time elapses and storage conditions permit. In fact, equilibrium is reached between the seeds and the air in the spaces between them when the net movement of moisture from air to seed, or from seed to air, is zero.

The relative humidity of the air is calculated with an electronic humidity measuring instrument, which also has a temperature control. The apparatus should be equipped with different probes for measurements in large and small seed lots packed in bags or seed containers. The measurements can be done without sampling the seed. The result should be calibrated against a moisture test done by the air-oven method. Table 2 gives the equilibrium moisture content of several crop seeds at different relative humidities, at approximately 15-25°C.

Table 2. Equilibrium moisture content at different relative humidities at approximately 15-25°C.

Scientific name	Common name	10	20	30	40	45	50	60	70	75	80	85	90	100
Allium cepa	onion	4.6	6.8	8.0		9.5		11.2		13.4				
Arachis hypogaea	groundnut	3.0	3.9	4.2	5.1		5.9	7.0	8.5		11.1		17.2	
Avena sativa	oats	5.6		8.4	9.9	10.2	11.2	12.5	14.3	15.3	16.8	18.6	22.3	24.1
Brassica oleracea	cabbage	3.2	4.6	5.4		6.4		7.6		9.6	10.0			
Daucus carota	carrot	4.4	5.8	6.9	7.9		8.9	10.0	11.9		14.2			
Glycine max	soya bean		5.5	6.5	7.1	7.5	8.0	9.3	11.5	13.1	14.8		18.8	
Gossypium spp.	cotton	3.7	5.2	6.3	6.9		7.8	9.1	10.1		12.9		19.6	
Hordeum vulgare	barley			8.3	9.8	10.6	11.4	13.2	15.0	16.1	17.2		22.7	26.8
Lycopersicon lycopersicum	tomato	3.2	5.0	6.3	7.5	7.8		9.2	11.1	12.0				
Medicago sativa	lucerne	4.8	6.4	7.8	9.0		10.0	11.7	14.0		15.0			
Oryza sativa	rice		7.5	8.6	10.3	10.7	11.3	12.8	13.7	14.6	15.2		18.4	
Phaseolus vulgaris	common bean	3.0	4.8	6.8		9.4		12.0		15.0	16.0			
Pisum sativum	pea	5.3	7.0	8.6	10.3		11.9	13.5	15.0		17.1		22.0	26.0
Secale cereale	rye	6.9	8.2	9.0	10.5	10.9	12.0	13.4	15.0	15.7	17.4	20.1	23.0	
Sorghum sudanense	Sudan grass			8.6		10.5		12.0		15.2			18.8	21.9
Trifolium hybridum	alsike clover			7.9					9.3		15.9	18.9		
Trifolium repens	ladino clover			7.2					8.7	10.9	15.4	18.0		
Trifolium pratense	red clover			7.6					9.1	11.2	15.6	18.7		
Triticum durum	durum wheat			8.5		10.0		11.5		14.1			19.3	26.6
Triticum aestivum	hard red spring wheat			8.5		10.1		11.8		14.8			19.7	25.0
Triticum aestivum	hard red winter wheat			8.5		10.5		12.5		14.6			19.7	25.0
Triticum aestivum	soft red winter wheat			8.6		10.6		11.9		14.6			19.7	25.6
Triticum aestivum	white wheat			8.6		9.9		11.8		15.0			19.7	26.3
Vicia faba	broad bean	4.2	5.8	7.2		9.3		11.1		14.5	17.2	22.6		
Vicia villosa	vetch								11.0	13.0	17.4	18.7		
Zea mays	maize	6.2	7.9	9.3	10.7		11.9	13.1	14.6	15.5	16.5		20.7	

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An Introduction to Purity Analysis (with emphasis on cereal and pulse seed)

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Introduction

Good seed should not have a high percentage of chaff, straw, sand, and weed seeds. In practice, however, it is impossible for cleaning machines to completely remove all these admixtures. Purity analysis determines exactly how much of the impurities remain, even if the percentage is very low.

Many countries, as well as the European Economic Community, have seed regulations to protect the buyer which prescribe the minimum quality standards for seed lots. In many countries, seed testing stations are associated with the International Seed Testing Association (ISTA), whose *International Rules for Seed Testing* (ISTA 1985) prescribes testing methods but does not set standards for seed lots.

Objectives of the Purity Test

The purity test has two objectives. The first is to determine the composition by weight of the sample being tested and, by inference, the composition of the seed lot. In other words, the composition of the sample is expressed as weight percentages. If a representative sample is used, the test results apply to the lot as well. The second objective is to determine the identity of the various species of seeds and inert matter particles in the sample. Thus, all seeds must be identified by scientific name, using the *ISTA List of Stabilized Plant Names* (ISTA 1983).

Preparation for the Purity Test

a. **Size of submitted sample:** The "submitted sample," sent to the seed testing station by a person, company, or sampling agency, is much too large for a single purity test. The submitted sample's minimum size is specified by species in Chapter 14 of this book, "Seed sampling," Table 1, Column 3. As shown in the table, a submitted sample of lentil seed, for instance, must weigh 600 g or more, whereas the purity test requires only 60 g. There are a number of reasons for this difference:

   - Sampling in the warehouse is inaccurate for smaller quantities.
   - The sample must be of sufficient size for all tests, including those for seed health, cytology (chromosome counts), cultivar determination, and others. (The moisture test requires a separate sample).
   - The seed testing station must sometimes perform a second test because results of the first (preferably done in duplicate) exceed tolerance limits.
   - A number count test for other species must often be done in addition to the purity test. This determines the number (not weight) of seeds of other species, in an amount of seed 10 times the sample size required for the purity test.
   - The sub-sample for the purity test cannot be extracted easily and reliably from amounts smaller than those specified in the table.
   - A certain amount of the submitted sample should be stored for one year, should re-testing be required.

b. **Preparation of the working sample:** Sub-samples are taken from the submitted sample for purity analysis. The sub-sample or working sample has the same composition as the submitted sample, but can be analyzed more quickly.

   The ISTA Rules give detailed prescriptions for sub-sampling equipment and procedures. For taking a purity working sample, which is preferably two independently-drawn half working samples, the Wageningen station combines the mechanical dividing and spoon methods, which suits the size and composition of most submitted samples, and enables the operator to work with optimal speed and efficiency. The mechanical divider minimizes any bias in the sub-sampling. The sample is thoroughly mixed by passing it through the divider several times before separating the portion required. The spoon method is used to reduce the sub-sample further, so that its weight is as close as possible to the minimum weight prescribed for the half working sample.

Various types of mechanical dividers are described in the ISTA Rules. The best is the soil divider (Fig. 1), which consists of a divider and three pouring pans (labelled a, b, and c in the figure).

The procedure for using the soil divider is as follows:

- The submitted sample seed is scattered evenly into the pouring pan a.
- The two receiving pans, b and c, are placed alongside the soil divider.
- Pan a is emptied into the hopper, allowing the seed to flow at about equal rates along the hopper's entire length, filling pan b with half of the submitted sample and pan c with half.
- Pan b is replaced by empty pan a.
- Pan b is emptied into the hopper, as was done with pan a, making equal parts (each one-fourth of the sample) flow into c and a.
- Pan a is replaced by the empty pan b, emptied into the hopper, and the procedure continued.

Fig. 1. Soil divider. The first of a series of halvings is shown. The three pouring pans are labelled (a), (b), and (c).

A submitted sample is thus reduced successively by half, until a sub-sample five to 10 times the prescribed weight of half the working sample is obtained.

The spoon method is then employed, using the tools shown in Fig. 2, as follows:

- The sub-sample is poured carefully with a side-to-side swing onto a shallow tray, making an even layer. The tray should not be shaken.
- With a straight-edged spoon (Fig. 2) in one hand and a straight-edged spatula in the other, small portions are transferred to the weighing beaker on a balance (Fig. 3). Each spoonful should not be more than one-tenth the weight of the prescribed working sample. Spoonfuls should be taken from the entire sub-sample, to prevent bias caused by segregating the seed layer either vertically or horizontally. Care should be taken to scrape the spoon over the bottom of the tray so the lower layer is not merely skimmed.
- The weighing beaker should be filled to no more than 5% of the prescribed weight, but not less. The operator should never remove the surplus; it should either be left (although the sample will take longer to analyze), or the process started again. In the latter case, the weighing beaker can be emptied back into the submitted sample bag and refilled with about 10 spoonfuls of the material left in the tray. (Figs. 4-6 show other equipment used in the purity test and discussed in detail later in this paper).

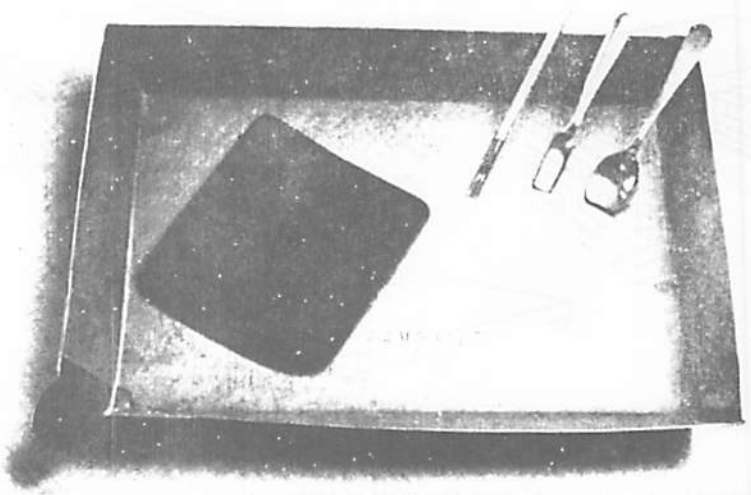

Fig. 2. Tools for the spoon method: tray, straight-edged spatula, and three straight-edged spoons.

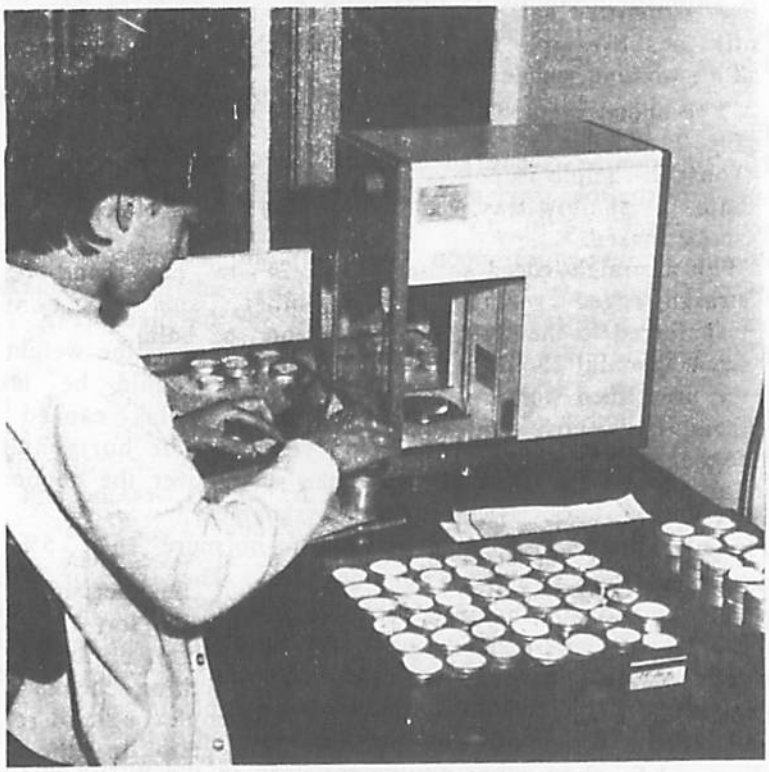

Fig. 3. Analytical balance.

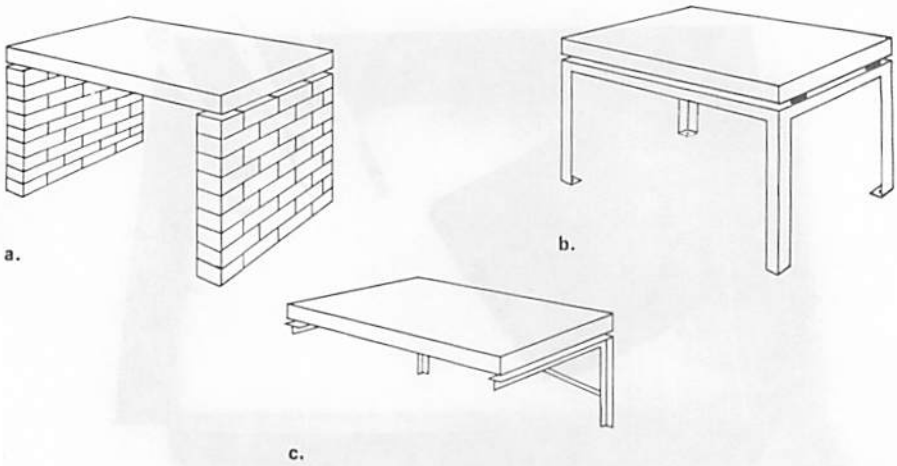

Fig. 4. Weighing tables: (a) and (b) show two types of tables that can be placed on the ground; note the rubber blocks (b) placed between the stone slab and the base. (c) can be used when a stable floor is unavailable.

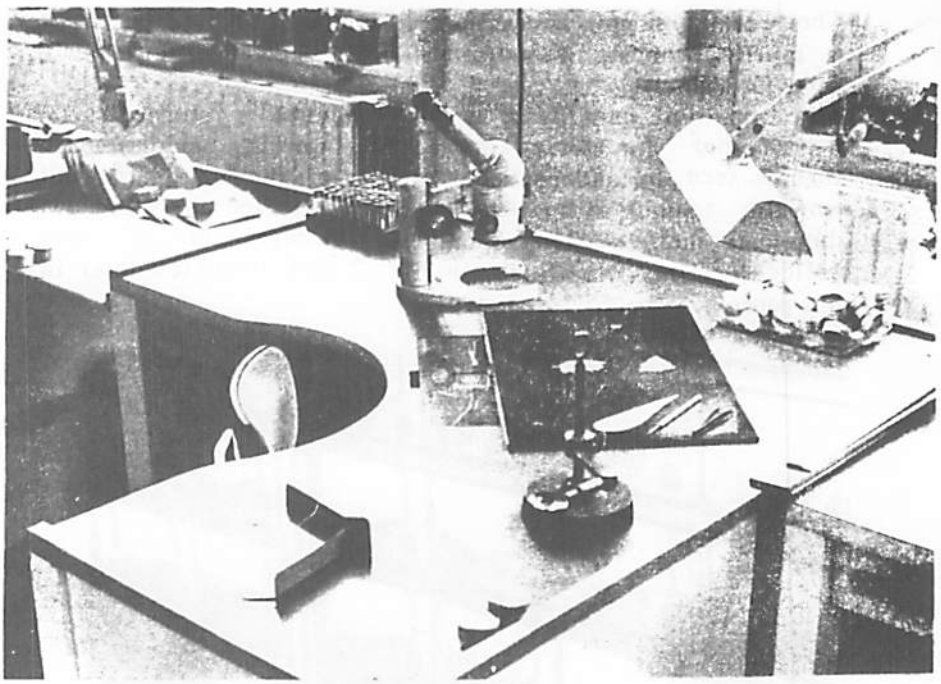

Fig. 5. Purity working table and tools.

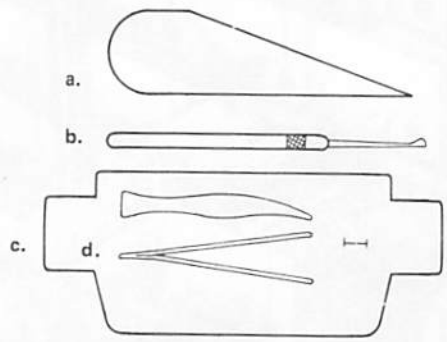

Fig. 6. Various small instruments: (a) flat spatula for purity test and counting seeds for germination; (b) scalpel needle, for same purposes; (c) scraper for removing and levelling sand in germination containers; and (d) tweezers, drawn from two angles.

The weight is recorded on a purity analysis form to serve as a check later on, when the working sample has undergone purity analysis and component weights added up. The initial weight and the sum of component weights may differ for unclear reasons; if the difference exceeds a certain figure, another test should be done. A suggested limit is 2% of the initial weight.

- The working sample is transferred from the weighing beaker to a purity working sample container, and taken to a purity table for analysis.
- The remaining quantity of submitted sample is returned to the bag, either for storage (for a whole working sample), or to furnish seed for independent drawing of the duplicate half working sample to confirm the first test (when analyzing two duplicate half working samples). (Storage of a seed collection is illustrated in Fig. 7 and discussed later in this paper.)

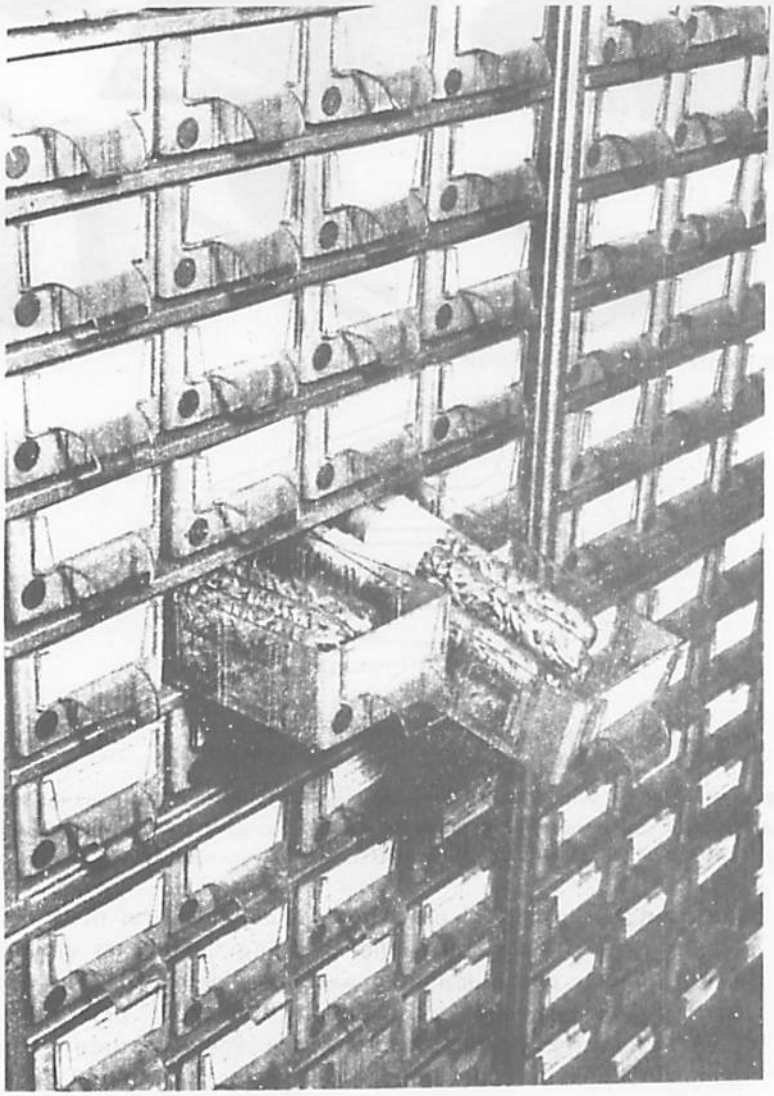

Fig. 7. Main seed collection.

Definitions of the Three Purity Test Components

The purity test procedure separates the sample's particles into three groups. Since 1976, the international certificate has listed only three components; "other crop seed" and "weed seed" are now combined into one fraction called "other seeds", since a species considered a weed in one country may be used as a crop in another. The receiving country receives a certificate listing all species in the lot and can then define "weeds" as appropriate. Many national certificates still have four components, however, and percentages of "other crop seed" and "weed seed" must be combined for international certification.

The ISTA Rules define the three components as follows:

a. **Pure seed**
The pure seed shall refer to the species stated by the sender, or found to predominate in the test, and shall include all botanical varieties and cultivars of that species. The following structures (even if immature, undersized, shrivelled, diseased or germinated, provided they can definitely be identified as of that species) shall be regarded as pure seed:

- Intact seeds (i.e., seeds in the botanical sense).
- Achenes and similar fruits, schizocarps, and mericarps with or without perianth and regardless of whether they contain a true seed, unless it is readily apparent that no true seed is present (refers to Compositae, Umbelliferae, etc.).
- Pieces of seeds, achenes, mericarps, and caryopses, resulting from breakage, that are more than one-half their original size. However, Leguminosae and Cruciferae seeds with the seed coats entirely removed shall be regarded as inert matter.
- Florets and caryopses of Gramineae as follows:

i. Florets and one-flowered spikelets with an obvious caryopsis containing endosperm. A sterile floret attached to a fertile floret in *Avena*, *Panicum*, and *Sorghum* is not removed but left attached and included in the pure seed fraction. In other genera, this sterile floret shall be detached and placed in the inert matter fraction.

ii. Free caryopses, and pieces of caryopses resulting from breakage that are more than one-half their original size.

b. Other seeds

Other seeds shall include seeds and seed-like structures of any plant species other than that of pure seed. With respect to classification as other seeds or inert matter, the distinguishing characteristics set out for pure seed shall also be applicable to other seeds, except in the case of *Cuscuta* spp. (see c(2), below).

c. Inert matter

Inert matter shall include seeds, seed-like structures and other matter as follows:

- *Seeds and seed-like structures*

1. Pieces of broken or damaged seeds; achenes; mericarps one-half the original size or less; seeds of Leguminosae and Cruciferae with the seed coats entirely removed; and structures defined in "Pure seed,b" in which it is readily apparent that no true seed is present.
2. Seeds of *Cuscuta* species that are fragile (frequently enlarged) or ashen grey to creamy white in color in section.

- *Other matter*

Soil, sand, stones, stems, leaves, pieces of bark, flowers, nematode galls, fungus bodies (such as ergot, other sclerotia, and bunt balls), and all other matter that is not seed.

Definitions of Pure Seed of Major Cereal and Pulse Crops (from Felfoldi 1983)

Only the structures described in the pure seed definition are classed as pure seed. All other structures among the seeds or attached to seed must be classed either as other seed or as inert matter, depending on the nature of the structure.

Sesamum

- Seed, with or without testa.
- Piece of seed larger than one-half the original size, with or without testa.

Arachus, Cicer, Glycine, Lens, Medicago, Phaseolus, Pisum, Trifolium, Vicia, Vigna

- Seed, provided a portion of the testa is attached.
- Piece of seed larger than one-half the original size, provided a portion of the testa is attached.

Avena (see Fig. 8)

- Spikelets, with lemma and palea enclosing a caryopsis, with or without awn, plus attached sterile floret.
- Floret, with lemma and palea enclosing a caryopsis, with or without awn.
- Caryopsis
- Piece of caryopsis larger than one-half the original size.

Note: - Separate spikelets consisting of two fertile florets.
- Do not separate units in which the lemma of the outer sterile floret partly envelops the inner fertile floret.
  Remove stalk at point of attachment.
- Single florets containing only the ovary are classed as inert matter.

Hordeum

- Floret, with lemma and palea enclosing a caryopsis, excluding entire awn when the length of the awn exceeds the length of the floret.
- Caryopsis.
- Piece of caryopsis larger than one-half the original size.

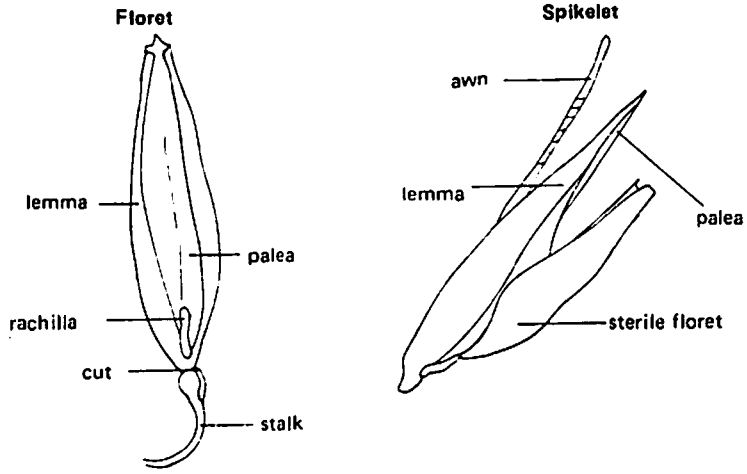

Fig. 8. Floret and spikelet of *Avena sativa.*

Oryza (see Fig. 9)

- Spikelet, with glumes, lemma, and palea enclosing a caryopsis, excluding entire awn when awn length exceeds floret length.
- Floret, with lemma and palea enclosing a caryopsis, excluding entire awn when awn length exceeds floret length.
- Caryopsis.
- Piece of caryopsis larger than one-half the original size.

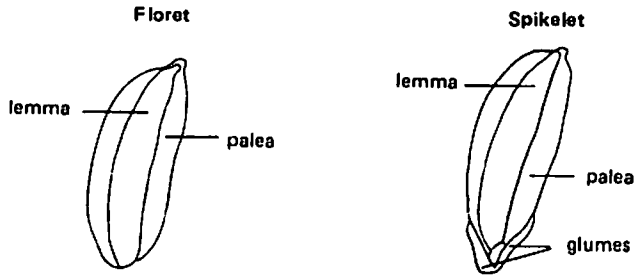

Fig. 9. Floret and spikelet of *Oryza sativa*.

Pennisitum (see Fig. 10).

- Fascicle of one-to-five spikelets with involucre of bristles. The spikelet must have glumes, lemma, and palea enclosing a caryopsis, plus attached sterile lemma.
- Floret, with lemma and palea enclosing a caryopsis.
- Caryopsis.
- Piece of caryopsis larger than one-half the original size.

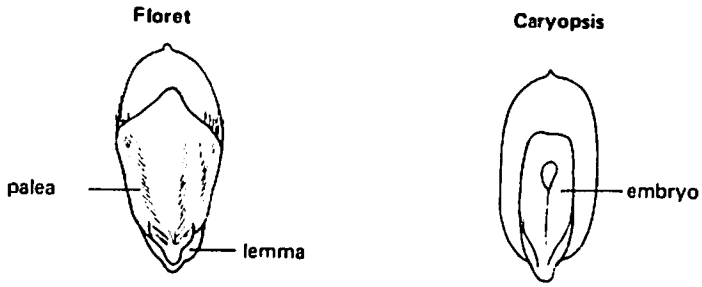

Fig. 10. Floret and caryopsis of *Pennisetum glaucum*.

Secale, Triticosecale, Triticum, Zea

- Caryopsis.
- Piece of caryopsis larger than one-half the original size.

Sorghum (see Fig. 11)

- Fertile (sessile) spikelet (with or without awn), with attached pedicel (of sterile spikelet) and rachis segment (stalk), provided that the stalk is not longer than the spikelet. (When the stalk is longer than the spikelet, the entire stalk is to be removed.)

  Note: The fertile spikelet consists of hardened glumes enclosing two florets (therefore not visible), one consisting of a transparent sterile lemma, the other containing the caryopsis within a tissue-like lemma and palea, with or without awn.

  - Caryopsis.
  - Piece of caryopsis larger than one-half the original size.

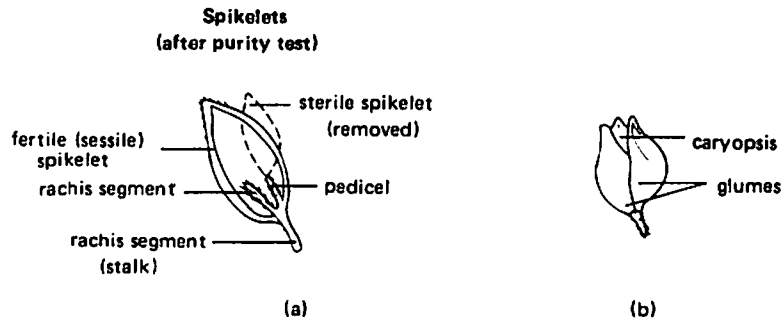

Fig. 11. Spikelets of (a) *Sorghum sudanense* and (b) *S. bicolor.*

Purity Test Procedure

a. Working sample

The purity analysis shall be made on a working sample taken from the submitted sample in accordance with Rule 2.7 and as explained in paragraph 3.b of the ISTA Rules.

The working sample should not be less than the weight indicated in Chapter 14: "Seed sampling," Table 1, Column 4; or, if the species is not mentioned, the sample should be of a weight estimated to contain at least 2500 seeds, subject to a minimum of 0.5 g and a maximum of 1000 g. The analysis may be made on one working sample of this weight or on two independently-drawn sub-samples, each of at least half this weight.

b. Separation

- The sub-sample (purity working sample) is spread on the working table.
- Each particle is judged individually based upon external appearance (shape, size, color, gloss, surface texture) and/or appearance in transmitted light.
- All other seeds and inert matter particles are removed, leaving the pure seed. (The separations result in the three components described earlier.)
- Seeds enclosed in fruits other than those cited under "Pure seed" shall be separated and the detached empty fruit classed as inert matter.
- After separation, each component part, any species of seed, and any type of other matter which requires a reported percentage shall be weighed in grams to the minimum number of decimal places necessary to calculate the percentage to one decimal place, and recorded on the purity form (paragraph 10 of the ISTA Rules).

Examples:

When the weight of sample (gms) is:	When the working sample and its components to the following number of decimal places:	Example of results (g):
<1	4	0.8036
1 - 9.999	3	8.036
10 - 99.9	2	80.36
100 - 999.9	1	803.6
⩾ 1000	0	8036

- Components may be retained for future reference; the pure seed, however, is sent to the germination unit, where 400 seeds will be used for the germination test.

c. **Tolerances**
   - If a duplicate analysis is made of two half-samples, the difference between the two must not exceed the tolerance between duplicate analyses given in Chapter 14 " Seed sampling," Table 2, Column 3. If the difference exceeds the tolerance, further pairs must be analyzed using the procedure given in the ISTA Rules.
   - When two or more purity analyses of whole working samples are made, the results must fall within the tolerance given in Chapter 14 "Seed sampling," Table 2, Column 4. These tolerances can also be used to compare results of different stations that have tested the same seed lot.

d. **Reporting results**
   The results of a purity test must be reported to one decimal place and the percentage of all components added together must total 100. Components of less than 0.05% should be reported as "trace". Components of 0.05-0.1% are reported as 0.1%. The Latin name of the species of pure seed, the Latin name of each species of other seed, and the kind of inert matter must also be reported.

Test Equipment

Optical aids: A magnifying glass of 3-5x magnification is very useful. A binocular microscope may be needed for the small-seeded species, or to determine the presence of species difficult to distinguish from the crop seed.

Balances: Balances intended for weighing samples, sub-samples, fractions, and components must meet certain requirements regarding precision.

The entire range of weights between 0.5-1000 g can be determined with two balances: an analytical balance accurate to 0.1 mg (capacity 160-200 g), and a precision balance accurate to 10 mg (with about 1 kg capacity) (see Table 1, Precision balance 1).

Table 1. Types of balances.

	Capacity (g)		Readability (mg)
Analytical balance	160	(200)	0.1
Precision balance 1	1000	(2000)	10
Precision balance 2	160	(220)	1

When many samples must be tested, either during the peak season or for moisture, it is necessary to have a third balance of an intermediate type (Table 1, Precision balance 2). The three balances should allow direct reading and have tare mechanisms.

Balances should be chosen that are made by a firm with a reliable service contract. The balances should be serviced at least once (preferably twice) a year.

Weighing table (Fig. 4): The balance should be placed on a weighing table, consisting of a stone slab 8 cm thick, resting on anti-vibration cushioning and supported by concrete or brick pillars. Weighing tables can be purchased from balance manufacturers, but are usually made locally. The weighing table must be situated on a concrete floor or against a brick wall.

Sieves: A set of small hand-sieves with different perforations can help to divide the working sample into two or more portions that are more homogeneous. This makes the test more accurate and speeds up analysis.

Other equipment (Figs. 5 and 6): Also required are spoons, spatulas, forceps, scalpel, needles, and shallow trays. Funnels and watch glasses are needed for normal purity analysis. It is better to put the working sample and its components into metal containers instead of paper bags.

Seed collection: The main seed collection should be stored in a

cupboard with metal units containing small plastic drawers. The seeds are put into labelled glass test tubes and stored in the drawers (Fig. 7). Also useful is a small collection for quick reference made up by each analyst. Specimen tubes of crop and weed seeds are arranged in holes in a wooden block (Fig. 5).

Special Tests

Several other tests, not actually part of the purity test, can be done by the purity department.

Number count test for other species (ISTA Rule 4): In international trade, this test is used mainly to identify seeds of noxious or undesirable species. The quantity of seed used for a purity test is insufficient for this test and usually must be increased tenfold. (See Chapter 14 "Seed sampling," Table 1, Column 5). The analyst counts only the number of seeds of each species cited by the sender or a given seed law; the sample is not separated into purity components. To determine any significant difference between determinations made by the same or different stations, refer to Table 4A of the ISTA Rules.

1000-seed weight (ISTA Rule 10): The 1000-seed weight is determined by the so-called weight determination. The procedure outlined in ISTA Rule 10 is rather complicated and less reliable than counting the number of seeds in the pure seed fraction of each half working sample (after completing the purity test). If results do not differ more than 2%, the average of the two halves can be used to calculate the weight per 1000 seeds.

Verification of species or cultivar (ISTA Rule 8): This test has many applications and is performed with different techniques, but must be done by an exceptionally skilled analyst.

Cytological test: For sugar beets and some grasses, the degree of ploidy is a major quality aspect. Triploid seeds of sugar beets, for instance, give rise to better crops than diploid or tetraploid seeds. Seed lots are always a mixture of all three types, however, and this test determines the presence of each, by counting the chromosomes in cells from squashed, stained root tips or from seedlings' primary leaves.

For *Beta*, the submitted sample must be fractioned with sieves to produce a representative working sample, and the chromosomes of 4 x 50 seeds counted. ISTA Rules do not describe this procedure, which requires special training to carry out.

Pelleted seed (ISTA Rules Annexes, Appendix A)

ISTA Rules Annexes give only provisional rules for testing pelleted seeds. The working procedure for normal seeds is followed, but the seeds are separated into fractions of pure pellets, unpelleted seed, and inert matter (ISTA Rules, Appendix A, 3.2). After weighing, 100 pellets from the pure pellet fraction are placed in water in a small container. After a few minutes, the contents are poured into a fine mesh sieve to trap the particles that were mixed with the pellets. The number of seeds of each species is counted and the type of inert matter specified (see complete explanation in the ISTA Rules, Appendix A, 3.4).

Purity Registration

Purity form: The purity form (Fig. 12), like the other forms, has two main sections separated by a double line; the lower section is for recording the analysis, and the upper section for final conclusions and additional information.

A purity test should be executed in duplicate on two sub-samples (or half working samples) drawn and tested independently (referred to as "1st Replicate" and "2nd Replicate" on the form). Two purity forms are therefore required: one for the results of the "2nd Replicate" and the other for the results of the "1st Replicate" along with the average of the two. This way, one analyst's results cannot bias the other's, since the two sets of results are compared after percentages have been calculated.

Filling out the form: When the submitted sample and its duplicate purity analysis forms are received, the purity section's leading analyst designates two analysts to draw the duplicate half working samples and to carry out the analyses.

Each analyst:

- confirms that the analysis number on the submitted sample's label is the same as the number on the form.
- writes the analysis number, species name, and "1st" or "2nd" on the working sample container, and signs it.
- draws a working sample (using the procedure outlined in this paper), weighs it, writes the weight at "working sample" at the top of the "grams" column of the form, dates it, and signs at "weighing working sample."

- subjects the working sample to blowing and encloses the fractions in separate containers (if the sample requires fractionation by blowing, either as an aid or to meet a requirement).
- records the blowing speed (i.e., manometer reading, or valve opening reading) on each container.
- records the blowing speed and the date, and signs at "blowing" on the form.
- takes the fractions and the form to a working table.

At the working table, the same or another analyst:
- subjects the sub-sample (fractionated or not) to a purity test.
- records the type of inert matter after "1" and the scientific or Latin names of other seeds after "2".
- records the scientific name of the pure seed at "Latin name of species (established by analyst)".
- records the date and signs in the "analysis" space.
- has data checked by the leading analyst.
- weighs the components in the weighing unit.

The leading analyst is responsible for all results reported. He/she signs and dates the form, confirming the name of the pure seed species (see *ISTA List of Stabilized Plant Names*, ISTA 1983), by writing it under "species as analyzed", and then sends the form to the office, if the calculation is performed by an administration center. In the office, the clerk:
- calculates the component percentages to two decimal places.
- compares the two series of percentages from the two replicates, and compares the difference with the prescribed table of tolerances.

If the difference between comparable percentages exceeds the tolerance, the analyst writes the analysis number in the upper right corner of a purity analysis form and orders an additional purity test.

If the difference between comparable percentages is within the tolerance, the analyst:
- writes the average percentage of the test in the column "average of replicates."
- rounds off these percentages to one decimal place.
- corrects the percentages so they total 100%, by correcting only the inert matter percentages. (Impurities present at less than 0.05% are reported as "trace" and not included in this calculation.)
- copies the corrected percentages at the head of the form.
- fills in the data for "1) kind of inert matter" and "2) kind of other seeds" in the center of the top of the form, for both replicates, and adds them up. The data are then ready to be reported on a report form (certificate).

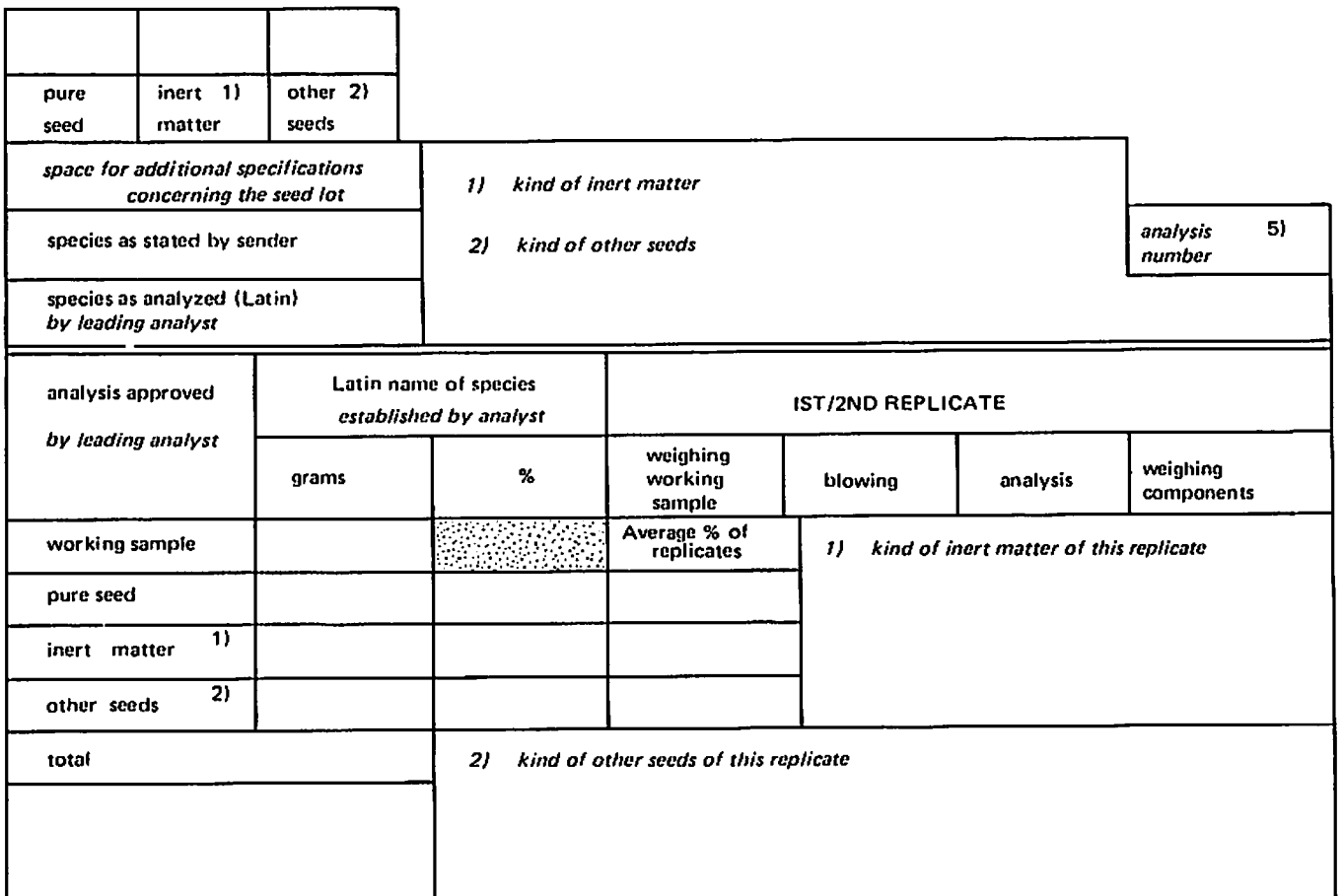

Fig. 12. Purity form. Each replicate requires a separate sheet.

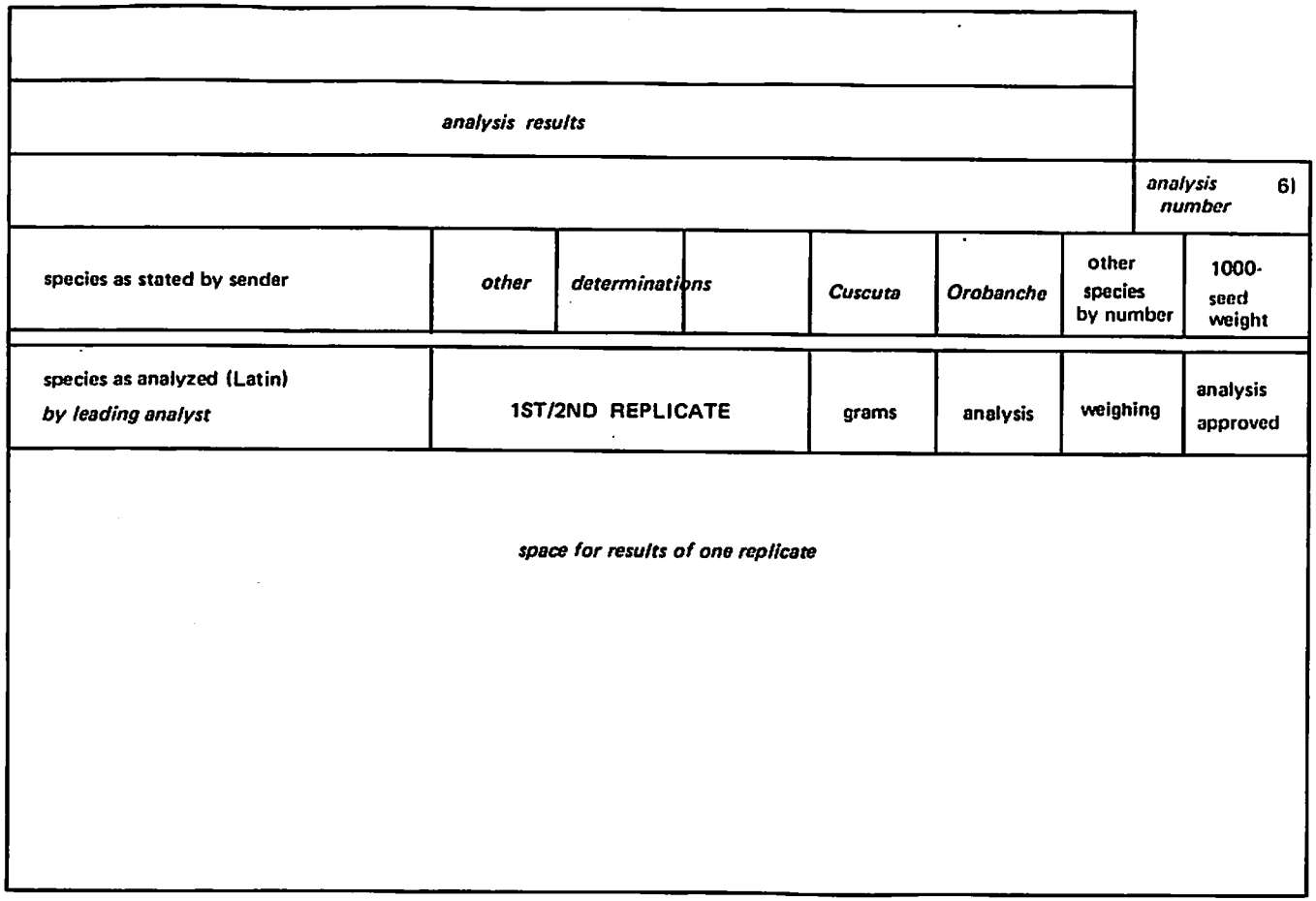

Fig. 13. Extra form.

The extra form (Fig. 13) is used to report special determinations that are normally reported under ISTA Certificate heading "Other Determinations". Such tests include: other seeds by number (number count test), 1000-seed weight, hectolitre or bushel weight, verification of species or cultivar, seed health, percentage of sprouted grain, percentage of cracked seeds, and others.

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Phenol Color Reaction for Varietal Identification of Wheat Seeds

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The phenol color test provides a useful tool for varietal identification, which is an important aspect of a good seed production program. Since Pieper (1922) showed that phenol tests could be used to identify wheat cultivars, several workers have standardized this test, including Esbo (1945), Korpinen (1964), and Walls (1965). The use of phenol color reaction is now one of the recommended tests for identification of wheat cultivars (International Seed Testing Association 1976).

The phenol test is a very simple method for classifying wheat cultivars into different color groups. Biochemical studies on phenol color reaction have shown that it involves the enzyme tyrosinase using phenol as a substrate (Esbo 1945). The seed coat is the site of biochemical reactions giving black, dark brown or mars brown, brown or snuff brown, light brown or deep olive, and negative color.

Often, however, more than one cultivar falls into a particular color group, making it difficult to identify a particular variety. Nonetheless, if observations are taken frequently during the development of color on the seed coat, it will be possible to further resolve varieties into the different color groups.

Experimental Procedure

Soak different cultivars of wheat in water overnight, preferably at 20°C. Line a petri dish (about 15 cm diameter) with two sheets of

filter paper. Saturate the filter paper with about 4 ml of 1% aqueous solution of phenol. Transfer the seeds onto the filter paper, cover the dish, and place it at temperature of 30°C for about four hours. Note the color reaction according to the following scale: black (+ + + +), dark brown (+ + +), brown (+ +), light brown (+), and negative (-).

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Physiology of Seed Germination and Dormancy

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Seed Germination

The resumption of active growth by the embryo resulting in rupture of the seed coat and emergence of a young plant is known as germination. In seed testing, however, the International Seed Testing Association (ISTA) defines germination in a laboratory test as the emergence from the seed embryo and development of those essential structures which indicate the ability of the seed type tested to develop into a normal plant under favorable conditions in the soil. A seedling is classified as normal only if it has the capacity for continued development into a normal plant.

Germination is of two types: hypogeal, in which the cotyledon does not emerge above the soil surface (e.g., pea); and epigeal, in which the cotyledon emerges above the soil surface (e.g., bean). Germination has four phases: imbibition, enzyme activation, cell elongation/division, and protrusion.

Factors Influencing Germination

Water, oxygen, temperature, and light all influence germination, although the first three are classified as essential.

1. *Water:* The extent to which imbibition of water occurs is determined by the chemical composition of the seed, the seed coat's permeability to water, and the availability of water in the environment. Imbibition is not related to seed viability.

   Seed swelling to some extent reflects the storage materials present in seeds. Protein is the chief water-imbibing component of seeds, although other components such as some cellulose parts and pectic compounds also swell. Starch, even in large amounts, does not add to the total swelling of seeds. Starch swells only at a very acidic pH or after treatment with high temperature, neither of which occur in nature.
2. *Oxygen:* The process of germination requires an expenditure of energy, therefore oxygen is essential for aerobic respiration.
3. *Temperature:* Different seeds germinate within different temperature ranges. Very low and very high temperatures prevent the germination of all seeds. The effect of temperature does not depend on other factors.
4. *Light:* The seeds of most cultivated plants usually germinate equally well in the dark or light. However, enhanced germination in light has been observed in freshly-harvested seeds of some species, e.g., lettuce (*Lactuca sativa*).

   The pigment phytochrome, responsible for absorbing light energy in seeds during germination, is protein in nature and blue in color. It exists in two forms: one which absorbs red light (P_r), and another which absorbs far-red light (P_{fr}). The nature of light given during the treatment determines the response. Red light (660 nm) promotes germination, whereas far-red light (730 nm) inhibits germination. The reaction is reversible as shown below:

Factors Promoting Seed Dormancy

The state of inhibited seed growth resulting from various internal causes is known as dormancy or rest period. Dormancy can be affected by the characteristics of the seed coat. The coat may be impermeable to water, as in many legumes and water lotus; impermeable to oxygen, as in *Xanthium*; or mechanically resistant, as in pigweed (*Amarnathus retroflexus*). The embryo's character also affects dormancy. Holly and European ash; for example, have rudimentary embryos, whereas apple and peach have dormant embryos. There are also germination inhibitors such as phenolic compounds (caffeic, ferulic, and abscisic acids).

Dormancy can be broken by scarification, low temperature (5-8°C), high temperature (40-45°C), alternate temperatures (20 and 30°C), and light. Various chemicals are also used to break dormancy (Table 1).

Table 1. Chemicals used to break dormancy.

Growth regulators	gibberellins; cytokinins; ethylene
Plant products	fusicoccin; cotylenol; cotylenin; strigol (root exudate of a host plant)
Respiratory inhibitors	azide; cyanide; malonate; hydrogen sulphide; carbon monoxide; sodium fluoride; iodoacetate; dinitrophenol; L- and D-chloramphenicol; hydroxylamine
Oxidants	hypochlorite; oxygen
Nitrogenous compounds	nitrate; nitrite; hydroxylamine; thiourea
Sulphydryl compounds	dithiothreitol; 2-mercaptoethanol; 2,3-dimercaptopropanol
Various	acetone; ethanol; ethyl ether; chloroform; methylene blue; carbon dioxide; phenols; hydroxyquinoline; dimethylglyoxime

In seed testing, however, potassium nitrate, gibberellic acid (GA_3), kinetin, sulphuric acid, and hydrochloric acid have frequently been used.

In a hormonal model proposed for the control of seed dormancy. the essential role of gibberellic acid and the enabling role of cytokinins in seed germination have been shown (Fig. 1). Gibberellins apparently have the primary role in regulating germination and in triggering the release of dormancy. The role of inhibitors such as abscisic acid and of cytokinins is secondary; i.e., preventive and permissive, respectively.

Without gibberellins

Inhibitor	Cytokinin −	Cytokinin +
	No germination	

With gibberellins

Inhibitor	Cytokinin −	Cytokinin +
−	Germination	Germination
+	No germination	Germination

Fig. 1. The essential role of gibberellins and the enabling role of cytokinins in seed germination.

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An Introduction to Germination Testing*

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Introduction

The aim of the germination test is to furnish reliable information on the field planting value of a seed. The test results can be used to compare the quality of different seed lots. The germination test must produce results that are uniform and reproducible within and between seed testing laboratories.

Testing under field conditions is normally unsatisfactory as the results cannot be repeated reliably, so laboratory methods have been developed in which most or all external conditions can be controlled to give the most regular, rapid, and complete germination for most samples of a particular kind of seed.

In a laboratory test, germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, indicate the seed's ability to produce normal plants under favorable conditions in soil. The conditions for laboratory germination, therefore, must not only be precise enough to initiate the seed's growth, but must also favor seedling development, in a limited period of time, to a stage in which all essential structures can be evaluated, to enable the separation of normal seedlings from abnormal ones without practical agricultural value. Germination is expressed as the percentage of pure seed of a given type of seed that produces normal seedlings under optimal conditions.

*Based on the International Seed Testing Association Rules.

Generally, if the seed to be tested is cleaned well, of reasonable quality, and not dormant, the results of the germination test performed under optimal laboratory conditions will correlate positively with emergence under practical sowing conditions. The germination test is not a precise forecast of emergence; instead, it indicates that under the same set of conditions a seed lot of relatively high quality will emerge better than a seed lot of lower quality. The International Seed Testing Association (ISTA) has developed germination methods and directions for seedling evaluation for international use, which are generally followed by different countries for national evaluation as well (ISTA 1985).

General Principles

The germination test should always be done on seeds from the pure seed fraction. From well-mixed pure seed, 400 seeds are counted at random into replicates of 100, 50, or 25 seeds. The seeds are spaced uniformly on a moist substratum, sufficiently separated to facilitate easy seedling evaluation and to prevent the seedlings from touching one another before they are counted and removed. This helps to prevent the spread of any infections.

The replicates are then placed under optimal germination conditions, usually including a treatment to break dormancy if needed. Fungicide treatment, although not used in an official germination test, may be undertaken upon request.

The first count is made when the majority of seedlings have reached the developmental stage at which proper evaluation is possible. Since the seedlings being tested are completely dependent for growth on reserve nutrients stored in the seed, they must be evaluated before they use up the nutrients and begin to rot.

The normal seedlings are removed and counted. Rotten seeds and decayed seedlings are also removed to prevent contamination and counted. Repeated counts are taken during the course of the test, following the same procedure. The final count also records the number of hard and fresh ungerminated seeds. If some seeds start to germinate only at the end of the test, the test can be prolonged. When the results of the test replicates fall within the maximum tolerated range, the average of the normal seedlings represents the percentage germination.

Procedures and Materials

Preparing the substratum

Substrata used in the germination test include paper, sand, and soil, depending on the laboratory's germination facilities, the seeds' dimensions, and the plants' light requirements. (Detailed specifications for paper, sand, and soil are given in the annexes of the ISTA Rules 1985, 5.4.A).

The substratum must be non-toxic and relatively free of molds, other microorganisms, and their spores. It must also provide adequate aeration and moisture for germinating seeds. The substratum must be sufficiently but not excessively moist for germination requirements. The initial quantity of water added depends on the substratum's nature and dimensions. To cut down on watering after planting, the relative humidity of the air around the seeds should be kept as close to saturation as possible. The pH value of the paper and sand should be 6.0-7.5.

Water

Tap water can be used to moisten the substratum, provided it is reasonably free from acidic, alkaline, organic or other impurities. Otherwise, distilled or deionised water should be used.

Paper

All paper substrates should be porous, but with a texture fine enough to prevent seedling roots from growing into the paper. For most seed types, the paper should not be so wet that a film of water forms around the finger when the moistened paper is pressed. Filter paper, blotter paper, or paper towels can be used to germinate seeds. Seeds can be placed on top of one or more layers of paper or, alternatively, germinated between two layers of paper (using envelopes, rolls, or "pleated" paper). Pleated paper seems to be a very good substratum for germinating seeds that are pelleted and those very susceptible to surplus moisture, because the test is normally carried out in closed boxes, making it possible to regulate moisture.

The paper substrates can be placed either directly on trays in a germination cabinet, in a room with humidity near saturation, or in closed boxes with a thick layer of moistened paper beneath the paper substrates.

Sand

Sand is normally used as a substrate for larger seeds such as cereals, peas, and beans. Depending on their size, the seeds can either be planted on a layer of sand and covered with 10-20 mm of loose sand, or planted atop the sand and pressed into its surface. The sand should be free from both fine and large particles; i.e., able to pass through a sieve with 0.8 mm diameter holes and be retained by a sieve with 0.05 mm diameter holes. When necessary, the sand must be washed and sterilized to kill microorganisms and foreign seeds. The amount of water added to the sand depends on the seeds' characteristics and size, but the sand should not be so wet that optimal aeration is prevented. For seeds of maize and large-seeded legumes, the sand should be moistened to approximately 60% of water-holding capacity. For most other species, the sand should be moistened to approximately 50% of complete saturation. The top and bottom layers of sand should be raked to enable good gas exchange.

The sand bed should then be prepared (Figs. 1-10), first by filling the germination pan with a levelled layer of moist sand (preferably with a metal scraper), and then loosening the sand with forceps or a rake. After the seeds are planted and covered to a depth of 1-2 cm, the sand cover is again loosened and levelled (without touching the seeds). The sand surplus is removed with the scraper but without pressing the sand.

Soil

Soil or an artificial compost is commonly used instead of sand to test samples that produce seedlings with phytotoxic symptoms when germinated in sand or paper. Such seedlings may become normal if the toxic substances can be absorbed by the humus complex of the soil.

The soil test is also used to confirm the evaluation of seedlings in doubtful cases, but it is not recommended for routine germination tests since soils are more difficult to standardize and therefore liable to cause greater variation between test results.

To moisten the soil, water should be added until the soil can be formed into a ball that is easily broken when pressed between two fingers. The soil should be further prepared as described earlier for sand.

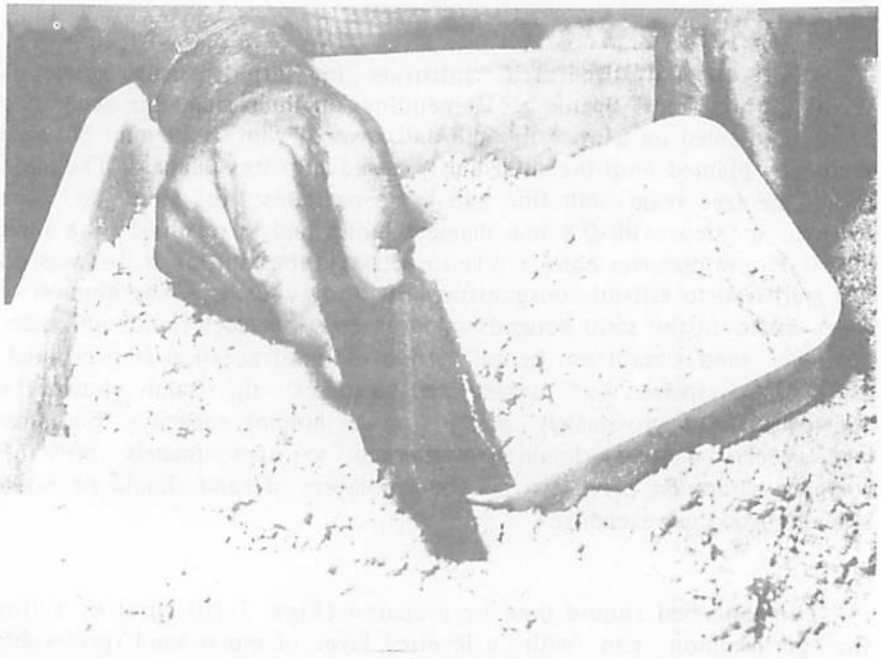

Fig. 1. Container is filled with moist sand and levelled with the aid of a scraper.

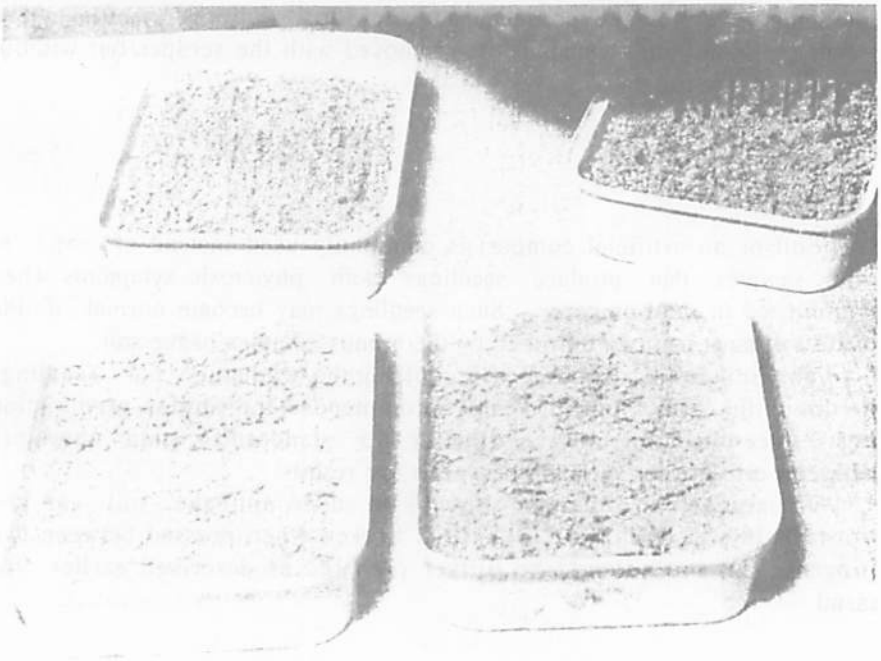

Fig. 2. The seed bed is loosened with a rake.

Fig. 3. Counting board is evenly filled with seeds.

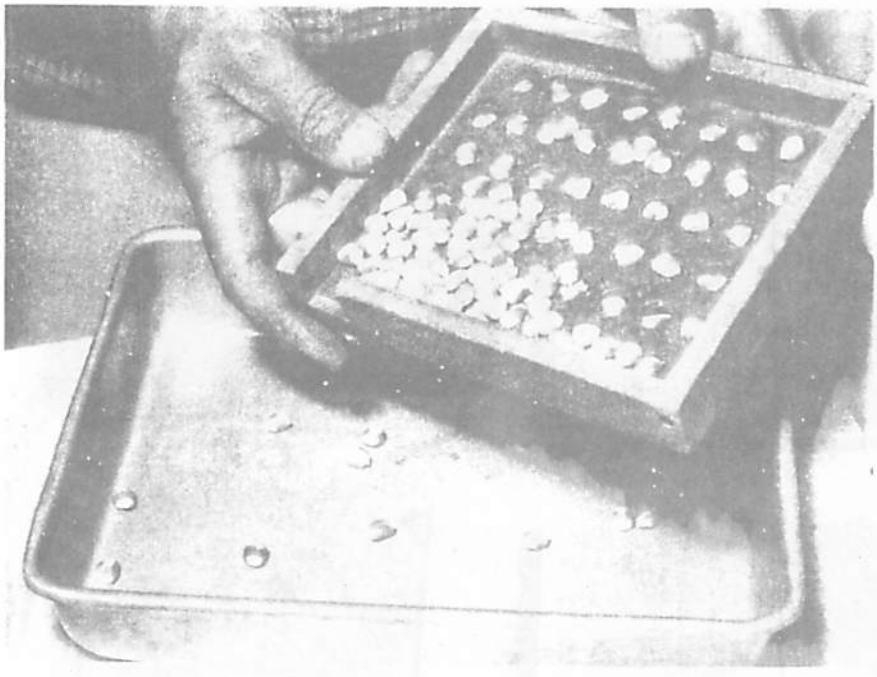

Fig. 4. Surplus of seeds is shaken off.

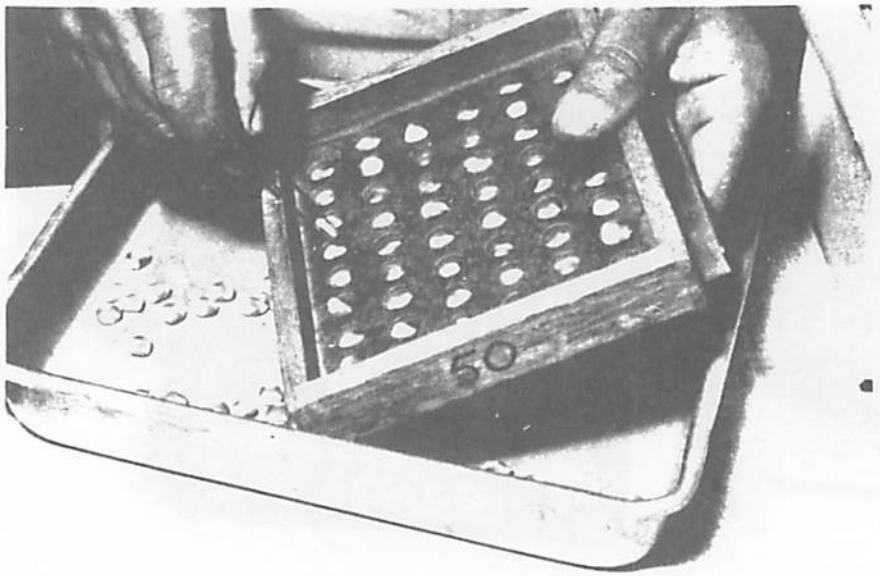

Fig. 5. The number of seeds is corrected, using tweezers.

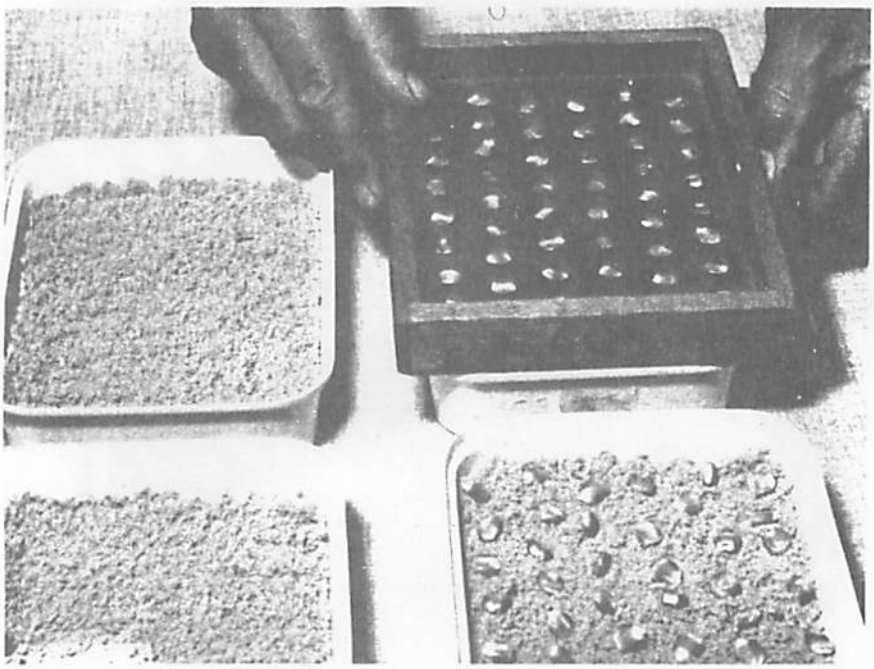

Fig. 6. The counting board is placed on top of the seed bed and the lower plate is pulled to release the seeds.

Fig. 7. Planted seeds are carefully covered with loose moist sand.

Fig. 8. The sand cover is carefully loosened and levelled with a rake, without touching the seeds.

Fig. 9. The surplus of sand is removed with the long side of the scraper.

Fig. 10. Slips with analysis number are inserted in the beds.

Preparing the replicates

The replicates of the working sample (the pure seed fraction) are either counted by hand or with mechanical devices such as vacuum counters and counting boards. Vacuum counters are usually used for smooth, non-hairy, and round-to-elliptical seeds (clovers, cabbages), with counting boards generally used for larger seeds (maize, peas, and beans).

Both vacuum heads and counting boards should be approximately the same size as the substratum in/on which the seeds are germinated. Because such counting devices are difficult to clean, different heads and boards should be used for chemically-treated and untreated seeds.

Hand counting (see Fig. 11)

The pure seed fraction is poured onto the working table, mixed well, and divided with a spatula into the same number of equal parts as replicates (e.g., 4 x 100, 8 x 50). Each part is mixed well again and the replicates counted at random.

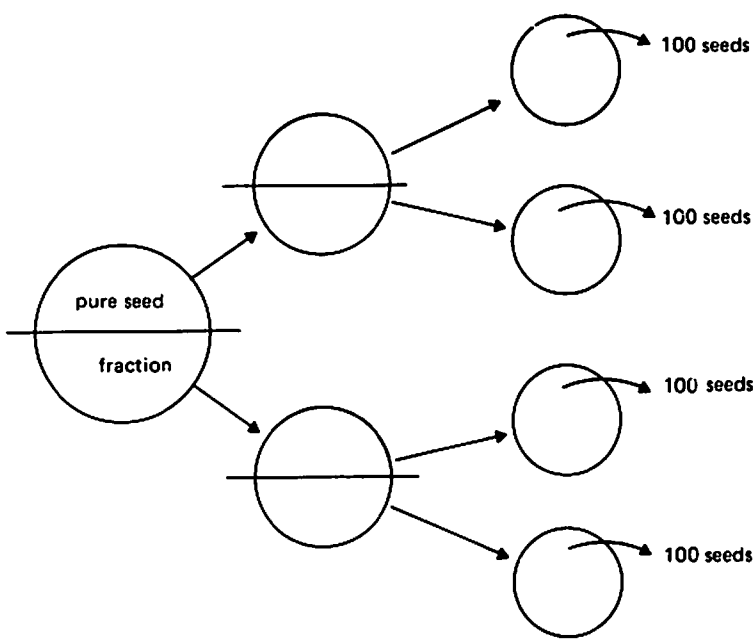

Fig. 11. Hand counting.

Vacuum counting (see Fig. 12)

The seeds are spread on the vacuum head whose plate is perforated with 50 or 100 holes; the seed is sucked against them when the vacuum is drawn. Vacuum counters should have interchangeable heads of various sizes, hole diameters, and hole numbers that are suited to the seed size and the substratum's dimensions.

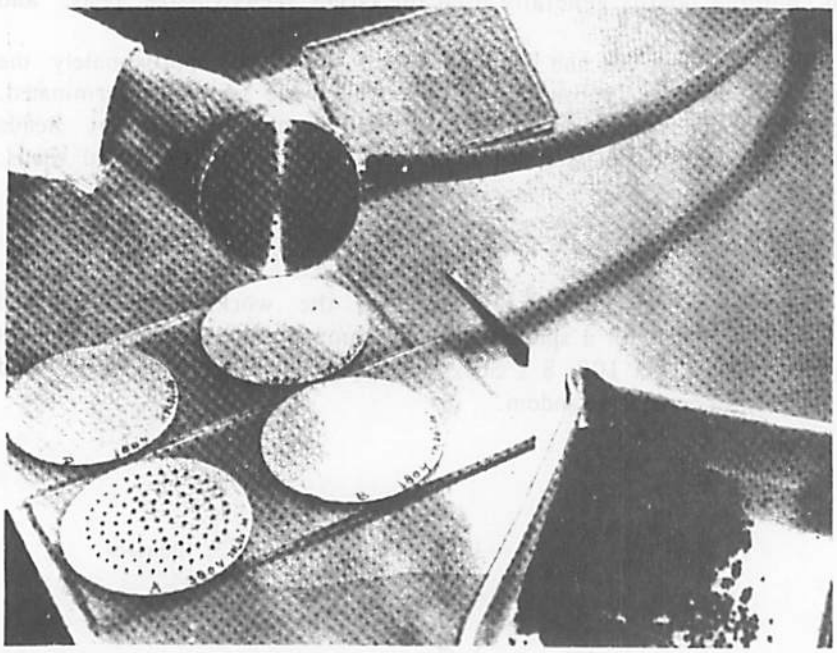

Fig. 12. Vacuum counting heads.

To prevent segregation, the entire surface of the counting head must be evenly filled with seeds before the vacuum is drawn. The excess seed is discarded by inverting the counting head, and holes which happen to have no seed or more than one seed are corrected. The counting head should never be placed face downward on a seed sample, as lighter seeds will be selected.

Counting board (see Figs. 3-6)

The counting board consists of two plates one above the other. Each plate has a number of holes (e.g., 50 or 100). The lower plate serves as a false bottom which can be slid back and forth so that, in a certain position, the holes in both plates correspond and the seeds fall into place upon the substratum. To avoid selection, the diameter of the counting board's holes should be wide enough for even the sample's largest seeds to fit in the holes.

Conditions

Temperature

Temperature is one of the most critical factors in laboratory germination testing. Different seeds often require different temperature ranges for germination, usually including an optimal temperature for the highest and most regular germination in the shortest time.

Growing conditions can affect the temperature requirements of the seed. Seeds may require either constant or alternating temperatures. Usually, when alternating temperatures are used, the lower temperature is maintained for 16 hours a day and the higher temperature for eight hours. The temperature changeover may last approximately three hours, but a sharp changeover of one hour or less may be necessary for dormant seeds. If the alternating temperatures cannot be controlled for a certain period (weekends, holidays), the seeds should be kept at the lower temperatures. The temperature should be kept as uniform as possible throughout the germination period and within the germination apparatus, with variation not exceeding $\pm$ 1°C in each 24 hour period. Testing should not be done in direct sunlight which could cause temperature to vary more than 1°C.

Light

Germinating seeds have varied light requirements. Some seeds germinate only in the dark, others require light, and others are not affected by light. In addition to promoting germination in some seeds, light fosters sturdier seedlings, which enable more certain evaluation of essential structures and also reduce the possibility of attack by microorganisms. The test should be executed in darkness only in the rare case when light retards germination.

For a germination test, daylight or artificial light can be used, but heat from the light source should not alter the germination temperature. Far-red light negatively affects germination of many seeds, while red light often promotes germination. Cool white fluorescent lamps are ideal because they emit relatively little far-red light and a great deal of red light.

Seedlings are usually exposed to light for eight hours in every 24; with alternating temperatures, light is provided during the high temperature period. The light should be approximately 750-1250 lux in intensity.

Additional treatments to break dormancy

Many viable seeds do not germinate under normally favorable germination conditions because of physiological dormancy, inhibiting substances, or hard seededness. The dormancy-breaking effect of light and alternating temperatures was already mentioned, but other treatments may be used, all of which require extreme care to prevent injuring the resultant seedling. Other germination-inducing treatments are:

- *Dry storage:* The seeds are stored for several weeks or months before germination.
- *Predrying:* The seeds are heated at a temperature not exceeding 40°C (usually 35°C), with free air circulation for up to seven days before the germination test.
- *Prechilling:* The seeds are placed on a moist substratum at a low temperature (5-10°C) for an initial period before removal to the required germination temperature. Prechilling usually takes one to seven days, but tree seeds often require a longer period (seven days to 12 months) and a lower temperature (1-5°C).
- *Potassium nitrate:* The substratum may be moistened with a 0.2% solution of KNO_3 (2 g/l of water). Water is used for subsequent moistening.
- *Gibberellic acid (GA_3):* It is known that plant regulators such as gibberellic acid, kinetine, ethylene, and auxins break dormancy in several seed types. In official laboratory germination testing, the use of GA_3 is allowed for only a few species.

  Depending on the degree of seed dormancy, the substratum is moistened with 200-1000 ppm solution of GA_3, prepared by dissolving 200-1000 mg GA_3 in one liter of water. For concentrations higher than 800 ppm, the GA_3 should be dissolved in a buffer solution prepared by dissolving 1.7799 g of $Na_2HPO_4.2H_2O$ and 1.3799g of $NaH_2PO_4.H_2O$ in one liter of distilled water.
- *Prewashing:* Natural inhibitors that are water-soluble may be removed by soaking and washing in water before the germination test. The water temperature is usually kept between 20 and 25°C. After this treatment, it may be necessary to remove the excess water before planting the seeds (e.g., *Beta*).
- *Modification of the seed coat and/or other structures:* This treatment is applied mainly to Leguminosae seeds and can be done by hand scarification--piercing, chipping or filing the testa with a needle, scalpel, or file at the cotyledon end of the seed--or by acid scarification. The latter treatment, although less labor-intensive, requires special care because the acid can damage the seed. As the time for soaking in acid can vary for different seed samples of the

same species, seeds must be regularly examined during treatment, and later washed thoroughly in running water for twice the duration of the acid treatment. Removing the seed pulp (e.g., *Tetragonia*) is also an accepted method to initiate germination.

Evaluation of the Test

The degree of correctness with which seedlings are assessed greatly influences the uniformity of test results. Seedlings can only be properly distinguished as normal or abnormal at a developmental stage in which all essential structures can be inspected, (Figs. 13 and 14), and before seedlings are running out of reserve nutrition stored in the endosperm, perisperm, or cotyledons. Whenever a sample produces seedlings which cannot be readily evaluated, another test should be made in good quality sand or soil under favorable conditions.

Normal seedlings

A normal seedling shows the capacity for continued development into a normal plant when grown in good quality soil with favorable water supply, temperature, and light. Normal seedlings can be completely intact or have slight defects or secondary infections. Detailed classification of normal seedlings is given in the ISTA Handbook for Seedling Evaluation (Bekendam and Grob 1979). Some examples of seedlings with slight defects are:

- Seedlings of which the primary root, hypocotyl, or epicotyl shows limited damage such as discolored or necrotic spots, splits, or cracks which are healed or limited in depth.
- Seedlings of *Zea*, all Malvaceae and Cucurbitaceae species, and large-seeded *Leguminosae* with a badly damaged primary root, but with a sufficient number of secondary roots.
- Seedlings of dicotyledons of which the cotyledons or the primary leaves are damaged, but not to such a degree that more than 50% of the total area of the cotyledons or primary leaves is not functioning normally.
- Seedlings of Gramineae of which the coleoptile or mesocotyl is superficially damaged.

Abnormal seedlings

An abnormal seedling does not show the capacity to develop into a normal plant when grown under favorable conditions in good quality soil. Detailed classification of abnormal seedlings is given in the

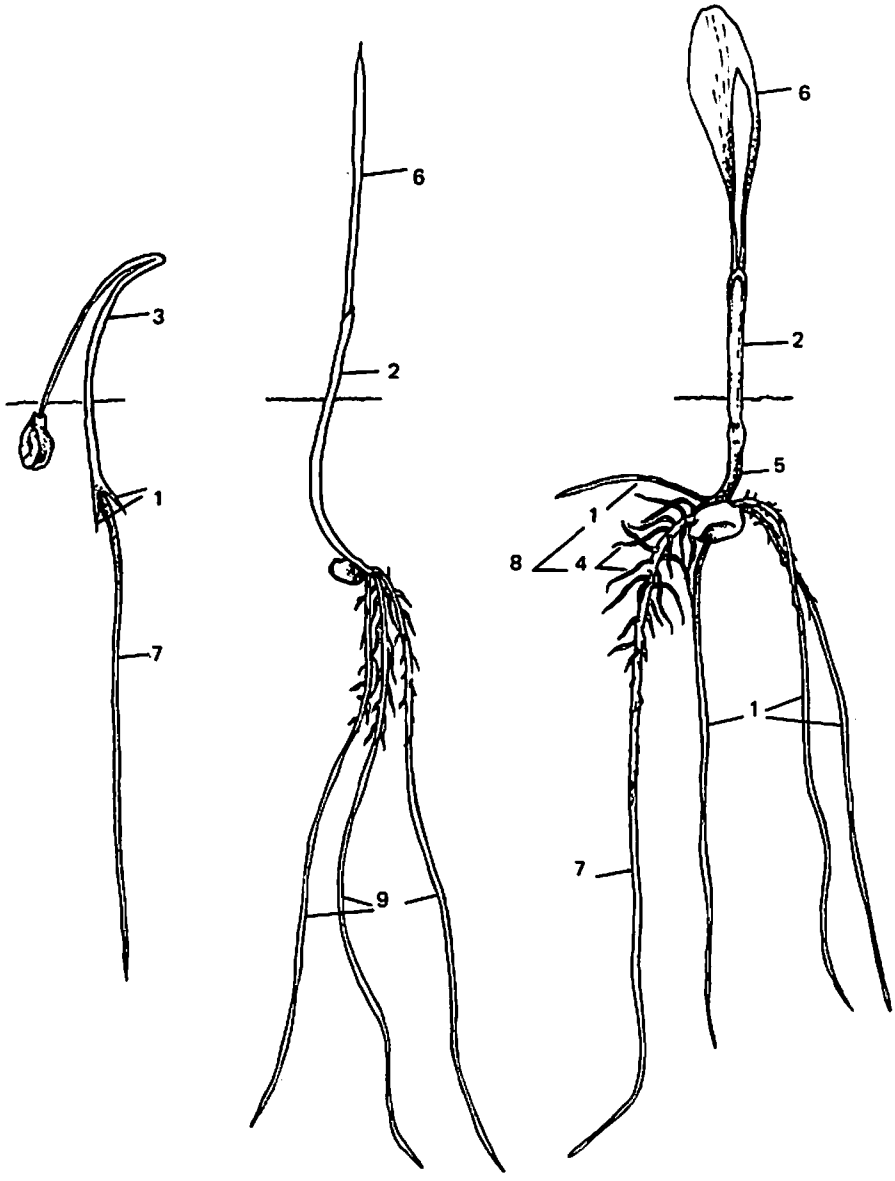

Fig. 13. The essential structures of monocotyledonous seedlings (from Bekendam and Grob 1979). (1) adventitious roots; (2) coleoptile; (3) cotyledon; (4) lateral roots; (5) mesocotyl; (6) primary leaf; (7) primary root; (8) secondary root; (9) seminal roots.

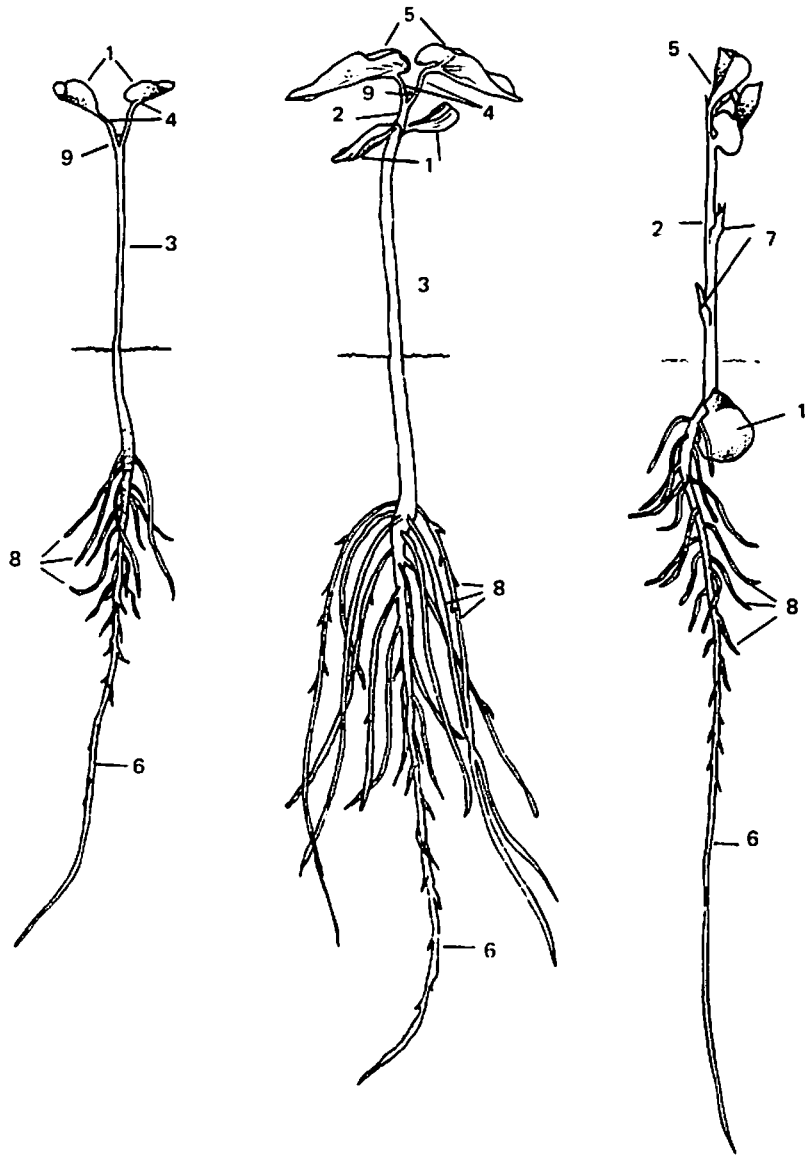

Fig. 14. The essential structures of dicotyledonous seedlings (from Bekendam and Grob 1979). (1) cotyledons; (2) epicotyl; (3) hypocotyl; (4) petiole; (5) primary leaves; (6) primary root; (7) scale leaves; (8) secondary roots; (9) terminal bud.

ISTA Handbook for Seedling Evaluation (Bekendam and Grob 1979). The three major classes of abnormal seedlings are:

- Damaged seedlings, in which any essential structure is missing or badly damaged.
- Deformed or unbalanced seedlings with an abnormality often caused by internal disturbances of a physiological/biochemical character (e.g., chlorophyll deficiency, roots with negative geotropism, and twisted, spindly or glassy seedlings).
- Decayed seedlings in which any essential structure is diseased or decayed from primary fungal or bacterial infection to the extent that normal development is prevented.

Hard seeds

Seeds that remain hard at the end of the test because the structure of the seed coat does not allow water absorption are classified as hard seeds (Leguminosae and Malvaceae).

Fresh ungerminated seeds

Seeds that are able to imbibe water but remain firm and apparently viable, even after appropriate treatment to break dormancy, are classified as fresh ungerminated seeds.

Dead seeds

Ungerminated seeds that are neither fresh nor hard are classified as dead seeds. They can be removed from the substratum at any count, but they must clearly be rotten. (Empty and insect-damaged seeds are usually considered dead seeds as well.)

Duration of the Test

The germination test varies in length according to the seed species, the type of substratum, the temperature, and the illumination. The chilling period for breaking dormancy is not part of the test period.

It is not possible to specify exactly when the first count should be taken, but it must be done when proper evaluation is possible. If the test period is long, intermediate counts may be necessary for seedlings that have reached a stage of development sufficient for evaluation, and also to remove badly decayed seedlings and rotten

seeds. The number of intermediate counts, however, should be kept to a minimum to reduce the risk of damaging insufficiently developed seedlings. More frequent counts are sometimes necessary when a sample contains seeds infected by fungi or bacteria.

In many cases, seeds tested in sand or soil are subject only to a final count. In official seed testing, a test may be prolonged for an additional period of seven days if some seeds have just started to germinate at the end of the test. The test can also be ended before the end of the official period when the analyst is certain that the sample shows maximum germination.

Recording and Calculating Test Results

Special pre-printed forms are useful to record the results of germination analyses (Fig. 15), as well as information on planting and counting dates, the location of the replicates, and the type of abnormalities. The form also facilitates calculation of the averages of different categories.

At the first count, the normal seedlings are removed and recorded (under N). Obviously rotten seeds and decayed seedlings are also removed and their numbers recorded (under D and A, respectively), along with the numbers of insufficiently developed seedlings and ungerminated seeds (under R). This procedure is repeated at subsequent intermediate counts. Seedlings classified as abnormal for any other reason than decay are not removed from the substratum (and not recorded as abnormal but included under R) until the final count, which allows the senior analyst to check the types of abnormalities.

On the last counting day, evaluation is completed. Hard and fresh ungerminated seeds are now also recorded (under H and F, respectively). The number of seeds and seedlings in different categories must equal the number of seeds originally planted ("missing" seeds are not acceptable).

When the numbers in the different categories of the four replicates of 100 seeds fall within the maximum tolerated range (refer to Table 5B of the ISTA Rules, 1985), the average value is calculated to the nearest whole number (0.50 and 0.75 are rounded upwards and 0.25 is rounded downwards). A second test is required if the results of the 100-seed replicates fall outside the maximum tolerated range; when results seem unreliable because of an incorrectly-conducted test, the spread of fungi or bacteria, the existence of phytotoxicity or dormancy; or because of incorrect seedling evaluation, calculation, or recording of results. When the results of the second and first tests do not match, one more test should be done.

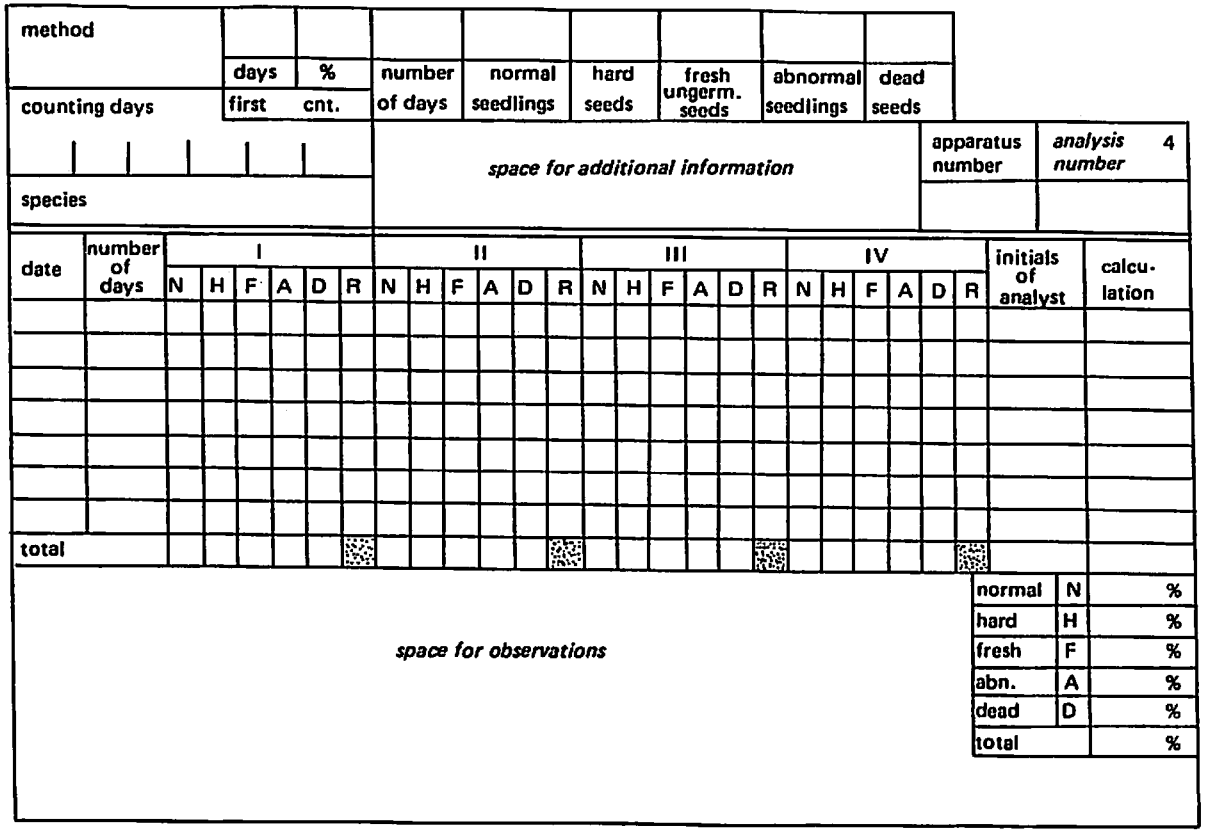

Fig. 15. Germination form.

Germination Apparatus

Different types of germination equipment are available to meet the following requirements:

- All constant or alternating temperatures between 5-35°C.
- Temperature tolerance not exceeding ± 1°C.
- A sharp change in temperature (between 10-30°C in less than one hour).
- Air humidity very close to saturation.
- Facilities for adequate illumination that does not affect test temperature and relative humidity.
- Automatic control and regulation.
- Easy repair or availability of interchangeable units.
- Easy to clean.

The apparatus used most widely in germination testing are the germination cabinet, the germination table, and the germination room. Apart from financial constraints, the choice of equipment depends on the number and kind of seeds to be tested. Laboratories should use germination rooms, for example, if they must test a large number of cereals in sand, which usually need pre-chilling. Whatever apparatus is selected, it should be serviced regularly and have a constant supply of clean water and electricity--admittedly difficult conditions to meet in many tropical and sub-tropical regions.

Germination cabinets

Cabinets may either be equipped for constant temperatures or for both constant and alternating temperatures. They may be "wet" cabinets for seed germination on open seedbeds, or "dry" cabinets in which the germination substratum must be provided with a cover in order to avoid dessication. (Wet cabinets are very efficient, but usually far more expensive than dry cabinets.) Temperature and light are usually controlled automatically.

Jacobson or Copenhagen tables

This apparatus consists of a plate for placing the filter papers with seeds. The papers are kept moist with a wick which extends from the seedbed, through slots or holes in the germination plate, into the underlying water bath. To prevent dessication, the seedbed is covered by a bell jar with a small hole in the top, which allows ventilation without excessive evaporation. Temperature is maintained either

indirectly by heating/cooling the water in the water bath, or directly by regulating the plate (usually done automatically). The entire unit is placed under artificial or natural light.

Germination rooms

Rooms can also be equipped for constant or for both constant and alternating temperatures. The rooms may be wet or dry, and with or without light facilities. Wet rooms are expensive to build, run, and maintain. Much cheaper and easier to operate are rooms in which only the temperature is controlled, by an air-conditioner; however, the germination substratum must be protected against dessication. Rooms can be furnished with shelves, but trolleys make it easier to transport material from one room to another, when alternating temperatures or prechilling are required.

Special Directions for Germinating Wheat, Barley, Chickpea, and Lentil

Details on germination media and apparatus can be found in the ISTA Rules (ISTA 1985), especially in paragraphs 5.4A, 5.5A, and 5.6A. Table 1 gives the specifications for the species discussed here.

The following is an extract from the ISTA Handbook for seedling evaluation (Bekendam and Grob 1979).

Table 1. Specifications for the germination test for different species.

Species	Substrate	Temperature (°C)	First count (days)	Final count (days)	Additional remarks
1. *Hordeum vulgare*	S; BP	20	4	7	Preheat (30-35 C); prechill; GA_3
2. *Triticum aestivum*	S; BP; TP	20	4	8	As for *Hordeum*
3. *Triticum durum*	S; BP; TP	20	4	8	As for *Hordeum*
4. *Cicer arietinum*	S; BP	20; 20-30	5	8	—
5. *Lens culinaris*	S; BP	20	5	10	Prechill

S = sand; BP = between paper; TP = top of paper; GA_3 = gibberellic acid.

Evaluation of wheat, barley, rye, and oats

The mature grain consists of a caryopsis, which may be naked (e.g., *Triticum*) or remain enclosed within the lemma and palea in the harvested unit (e.g., *Hordeum*). The embryo is situated at one end of the caryopsis. The scutellum remains in direct contact with the endosperm, which forms the main food reserves. The embryonic axis consists at its lower end of the radicle and a specific number of initials of seminal roots. The radicle is protected by a sheath, the coleorrhiza. The plumule at the upper end of the embryonic axis is also surrounded by a protective sheath, the coleoptile. The part of the seedling axis between the attachment of the scutellum and the coleoptile is termed the mesocotyl.

At the start of germination, the coleorrhiza breaks through the pericarp and the primary root pushes through the coleorrhiza followed almost simultaneously by the other seminal roots. The appearance of the seminal roots is followed by the elongation of the coleoptile with the first leaf developing inside, which later in the test emerges from the coleoptile near the tip. The mesocotyl may elongate considerably depending on the species tested and in response to test conditions.

Normal seedlings have:

- At least two seminal roots intact or with only slight defects (discolored or necrotic spots).
- The mesocotyl (where developed) intact or with only slight defects.
- The coleoptile intact or with only slight defects (discolored or necrotic spots, loose twists, or the coleoptile split for one-third or less from the tip).
- The leaf intact, emerging through the coleoptile near the tip (or at least reaching halfway up), or with only slight defects (discolored or necrotic spots or slight damage).

Tests should not be evaluated before the first leaf has emerged from the coleoptile in most seedlings. Seedlings which have not reached this stage of development at the end of the first period are considered normal if otherwise normal, unless the leaf extends less than halfway up the coleoptile.

Seedlings with a split coleoptile are considered normal when the split runs down from the tip to one-third or less of the coleoptile length. If the split extends to more than one-third the length, or if the coleoptile is split at its base, the seedling must be classed abnormal. When the length of the split is assessed, care should be taken not to enlarge the split by handling the seedling.

A seedling with a coleoptile trapped by the glumes or the fruit coat is considered normal when development is otherwise normal, but abnormal if development is considerably retarded.

Seeds of chemically-treated cereals germinated on an artificial substrate, especially paper, often produce seedlings with phytotoxic symptoms, such as short and swollen coleoptiles and stubby seminal roots. If a number of such seedlings are found in a test, a new test should be conducted in soil, which will absorb some of the chemical and reduce or eliminate phytotoxic symptoms. All seedlings which show phytotoxic symptoms even in soil are considered abnormal.

Evaluation of chickpea, lentil, peas, and *Vicia* spp.

These are dicotyledons with hypogeal germination. The shoot system consists of an elongated epicotyl and the terminal bud with developing primary leaves. The cotyledons usually remain inside the seed coat. The hypocotyl is not visible.

The root system consists of a primary root, usually with root hairs, and secondary roots which are to be taken into account, if the primary root is defective.

The embryos of mature seeds in the genera of this group have two large, fleshy cotyledons containing the food reserve. At the start of germination, the primary root emerges through the testa and elongates rapidly, and secondary roots soon develop. The hypocotyl is hardly discernible, but the epicotyl elongates considerably. In many genera of this group (e.g., *Vicia* and *Pisum*) the epicotyl carries one to three scale leaves below the primary foliage leaves and the terminal bud. The bud in the axil of each cotyledon normally remains dormant unless the terminal bud is seriously damaged.

Normal seedlings have:

- The primary root intact or with only slight defects, discolored or necrotic spots, healed cracks or splits, or cracks and splits of limited depth. (Note: Seedlings are also classed as normal when the primary root is defective but a sufficient number of normal secondary roots have developed.)
- The cotyledons intact or with only slight defects (less than 50% of the original tissue not functioning, or three cotyledons).
- The epicotyl intact or with only slight defects (discolored or necrotic spots; healed cracks, splits, or breaks; cracks or splits of limited depth; or loose twists).
- The primary leaves intact or with only slight defects (less than 50% of the area not functioning).
- The terminal bud intact.

The point of attachment of the cotyledons should be inspected for signs of decay or disease. Also, when the main shoot does not develop satisfactorily, the seedling is classed as abnormal, even if axillary shoots have developed.

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Tetrazolium Test for Seed Viability

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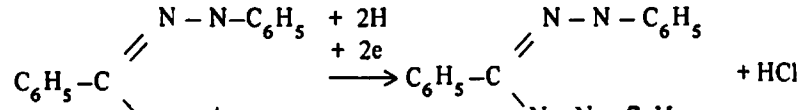
The tetrazolium test was developed in Germany by Lakon in the 1940s, and introduced in the USA after World War II. The test was developed to furnish a quick estimate of seed viability.

The living embryo or root-shoot axis of seeds converts absorbed colorless tetrazolium solution into a red colored substance called formazen. The reaction by which the color develops is as follows:



2, 3, 5 triphenyl tetrazolium chloride

triphenyl formazan (red in color)

Method

1. Wheat and chickpea seeds should be soaked overnight in water at room temperature.
2. The water-soaked seeds are then cut longitudinally (e.g., wheat, maize) or laterally (e.g., small-seeded grasses) to expose the embryo. Seed coats of dicots (e.g., *Cicer*) should be removed to facilitate the quick penetration of tetrazolium.
3. After the desired number of seeds are prepared they should be soaked in 1.0% solution of tetrazolium (TZ) of pH 6-7 and kept, preferably in darkness, at 30°C for 3-4 hrs. Temperature influences the reaction; e.g., at 26°C, staining will be twice as fast as at 20°C, and 32°C, twice as fast as at 26°C. It is preferable not to conduct the test above 40°C. If the acidity of the TZ solution is much higher, the color will not develop even on viable embryos. Solution with pH values progressively lower than 6 tends to be reflected first by weaker staining and later by failure

to stain. On the other hand, solutions with pH values progressively higher than optimum reflect progressively darker staining. There may be problems with evaluation at exceedingly high pH values.

4. When the color has developed, the TZ solution should be drained, and the seed should be rinsed two or three times with water and evaluated. During evaluation, seeds should be immersed in water. If it is impossible to evaluate seeds the same day, the stained seeds may be kept in a refrigerator in water for one or two days. Staining patterns for *Triticum aestivum* (wheat) are given in Fig. 1

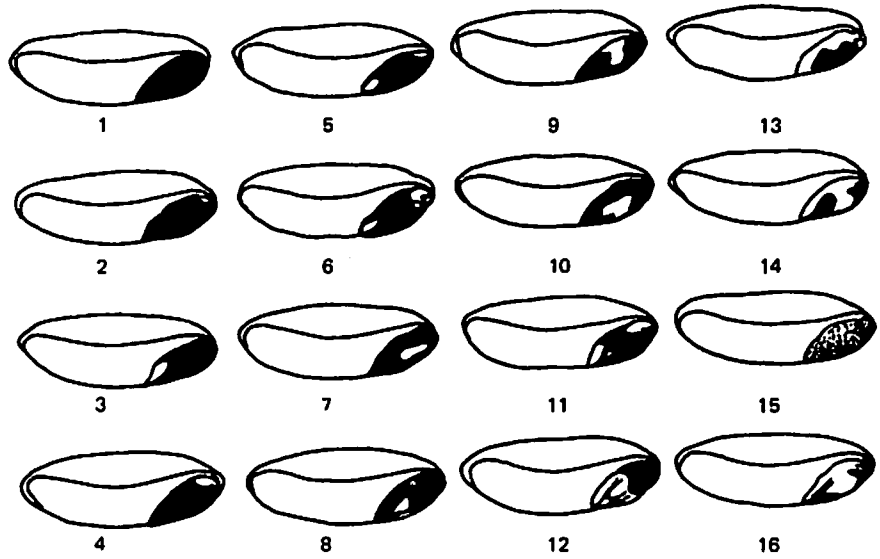


Fig. 1. Wheat: tetrazolium staining patterns for germinable and non-germinable seed. (Based on International Seed Testing Association diagram.)

Criteria for interpreting tetrazolium test results on wheat seed. Black areas indicate stained, living tissue; white represent unstained and dead tissue.

No. 1	GERMINABLE. Entire embryo stained bright red.
No. 2-5	GERMINABLE. Extremities of scutellum unstained.
No. 6	GERMINABLE. Extremities of scutellum, radicle tip, and coleorhiza unstained.
No. 7	NON-GERMINABLE. More than three-fourths of radicle unstained.
No. 8	NON-GERMINABLE. Plumule unstained.
No. 9	NON-GERMINABLE. Central portion of scutellum and scutellar node unstained.
No. 10	NON-GERMINABLE. Embryonic axis unstained.
No. 11	NON-GERMINABLE. Extremities of scutellum and plumule tip unstained.
No. 12	NON-GERMINABLE. Entire upper half of embryo unstained.
No. 13	NON-GERMINABLE. Scutellum unstained.
No. 14	NON-GERMINABLE. Scutellum radicle, and coleorhiza unstained.
No. 15	NON-GERMINABLE. Stain very faint pink.
No. 16	NON-GERMINABLE. Entire embryo unstained.

and for a typical dicot seed in Fig. 2. Many seeds are neither completely dead nor completely alive, therefore staining patterns should be correlated with the seedling descriptions (Figs. 3 and 4).

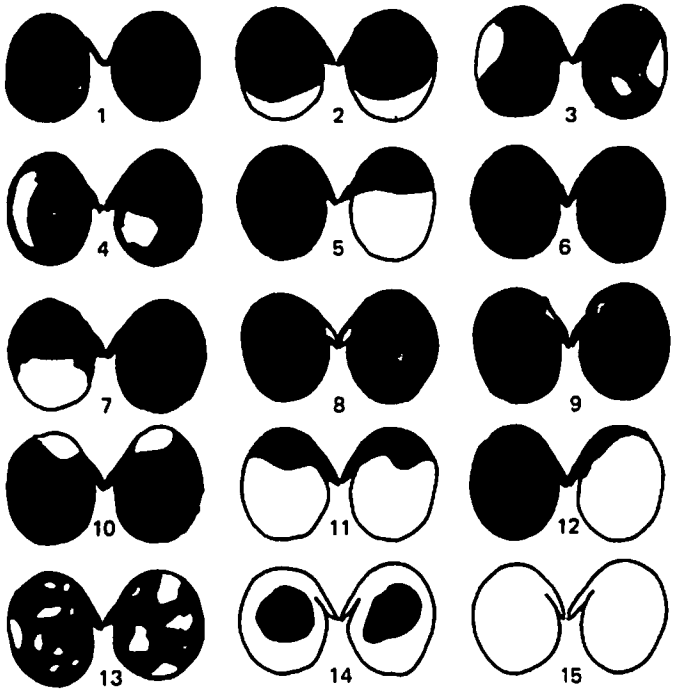


Fig. 2. Tetrazolium staining patterns and non-germinable seeds.*

Criteria for interpreting tetrazolium test results of hairy vetch seeds. Illustrations are paired and depict both sides of seed. Black areas indicate stained, living tissue; white areas represent unstained and dead tissue.

No. 1	GERMINABLE. Seed completely stained.
Nos. 2-5	GERMINABLE. Non-critical, unstained areas on cotyledons.
No. 6	GERMINABLE. Extreme tip of radicle unstained.
No. 7	GERMINABLE. Extreme tip of radicle unstained: one-half of one cotyledon unstained.
No. 8	NON-GERMINABLE. More than extreme tip of radicle unstained.
No. 9	NON-GERMINABLE. Unstained area on upper portion of radicle.
No. 10	NON-GERMINABLE. Juncture of radicle and cotyledons unstained.
No. 11	NON-GERMINABLE. More than one-half of cotyledonary tissue unstained.
No. 12	NON-GERMINABLE. One cotyledon almost entirely unstained.
No. 13	NON-GERMINABLE. Extensive mottled areas of unstained tissue.
No. 14	NON-GERMINABLE. Only small central portion of cotyledons stained.
No. 15	NON-GERMINABLE. Seed completely unstained.

*Based on International Seed Testing Association diagram.

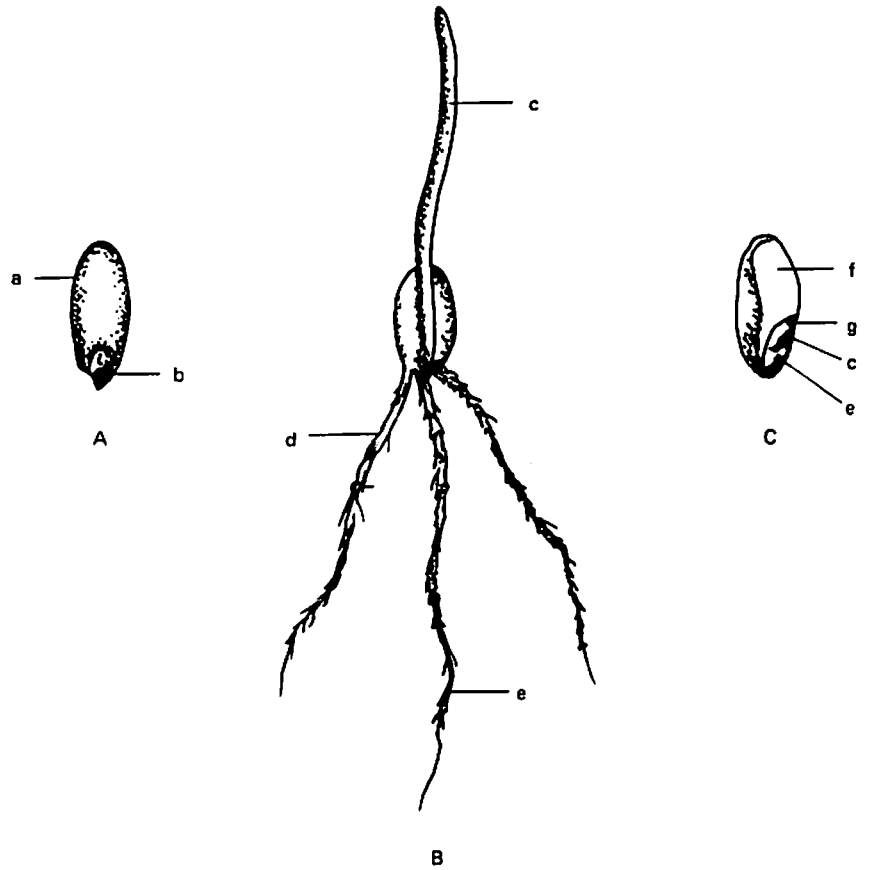


Fig. 3. Wheat: seed and seedling structure. A, intact seed; B, seedling; C, bisected seed. a, pericarp; b, germ; c, plumule; d, secondary root; e, primary root radicle; f, endosperm; g, scutellum. (Based on International Seed Testing Association diagram.)

Accurate interpretation of the tetrazolium test depends upon knowledge of seed and seedling structures, understanding of the mechanism of the test and its limitations, the interpretation of staining patterns combined with other visible aspects of seed quality, and experience with the method.

The analyst should be familiar with cell division areas in embryos. In grasses, these areas include the radicle tips, the seminal roots, and the plumule bases. If a dead area includes mesocotyl and seminal roots, the embryo cannot develop into a seedling. In wheat and rye, the tips of coleorhizas are frequently injured or dead. In maize that has been shelled at high moisture, the upper and lower tips of scutellum frequently fail to stain. These symptoms do not necessarily prevent germination under favorable conditions, especially if seeds are

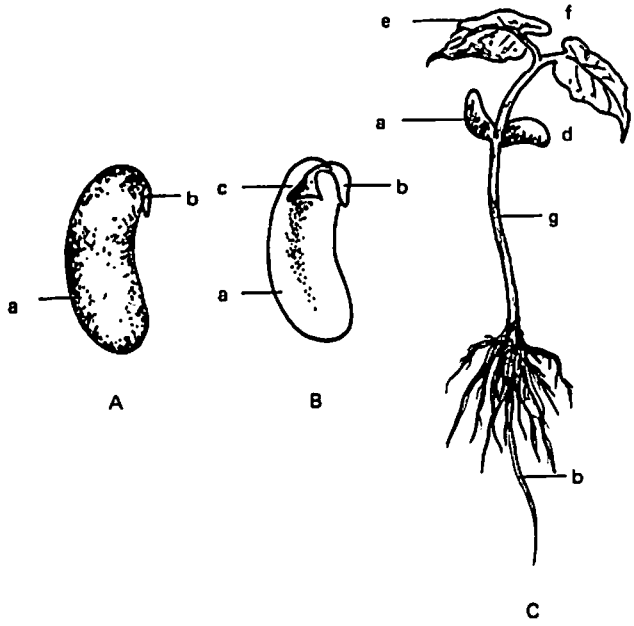


Fig. 4. Beans: seed and seedling structure. A, external view, seed coat removed; B, interior view, one cotyledon removed; C, seedling. a, cotyledon; b, radicle; c, plumule; d, epicotyl; e, primary leaf; f, growing point; g, hypocotyl. (Based on International Seed Testing Association diagram.)

properly treated with a suitable fungicide. Damage to legume seed frequently occurs in hypocotyls and at points of attachment of cotyledons and hypocotyls. Injuries that involve growing points, or those occuring between or adjacent to essential structures, are more critical than injuries that are of similar magnitude but occur in more remote regions, such as in cotyledon tips. All of these points should be considered when deciding whether seed is germinable or not.

Results from properly conducted TZ and germination tests are generally close. High quality seed usually gives closer results than low quality seed.

Discrepancies in results between the TZ and germination tests may have various causes including sample differences, improper germination testing, improper TZ test techniques, dormant seed, hard seed, or seed-borne organisms. Another reason might be chemical injury; fumigation, injury, and excessive mercurial seed treatment may not be detected with the TZ test. The chemical damage that prevents normal germination may not inhibit the TZ staining process.

When the pigment within the seed coat or lemma prevents clear viewing, a few drops of a lactophenol clearing solution can be used, composed of lactic acid, phenol, glycerin, and water in a ratio of

20:20:40:20. Removal of pigmentation from the covering structure requires about 10-30 minutes.

In summary, the TZ test gives a quick estimate of viability (within 12-20 hours). With dormant or slow-germinating seed, a viability test is extremely useful. In the TZ test, seeds are not damaged by analysis, so they can still be germinated. On the other hand, it is difficult with the test to distinguish between normal and abnormal seedlings. The TZ test also does not differentiate between dormant and non-dormant seeds, and since the test does not involve germination, microorganisms harmful to germinating seedlings are not detected.

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Seed Vigor: Concepts and Measurement

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In seed evaluation, germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, indicate its ability to produce a normal plant under favorable conditions. Procedures for determining germination percentage have been perfected and standardized so that different laboratories obtain remarkably uniform results when testing seeds of the same lot.

Conditions used for the standard germination test, however, are almost in direct contrast with conditions to which seeds are normally subjected in the field. In the standard germination test, weak, deteriorated seeds may be capable of producing a normal seedling, because moisture and temperature during the test are optimum and the germination substrata, unlike soil, are not loaded with microorganisms, herbicides, fertilizers, fungicides or systemic insecticides. In many instances, seed lots of apparently equal quality as indicated by germination percentage will produce largely different responses in field emergence. Therefore, determining "the degree of aliveness" (vigor) of a seed is just as important as determining whether the seed is alive.

Below are some examples of the large differences between field and laboratory germination percentages:

	Lot	Lab germination (%)	Field emergence (%)
Pea	A	70	32
	B	65	69
	C	45	42
Onion	A	63	60
	B	65	27

Variations such as these arise due to differences in vigor of seeds in a seed lot. Clearly, a germination test alone is not enough to assess seed quality.

Isley (1957), in one of the first attempts to conceptualize seed vigor, defined it as "the sum total of all seed attributes which favor stand establishment under unfavorable field conditions." Fig. 1 illustrates Isley's concept. His definition, however, was criticized by many seed technologists because it emphasizes the environment (unfavorable field conditions) instead of the seed.

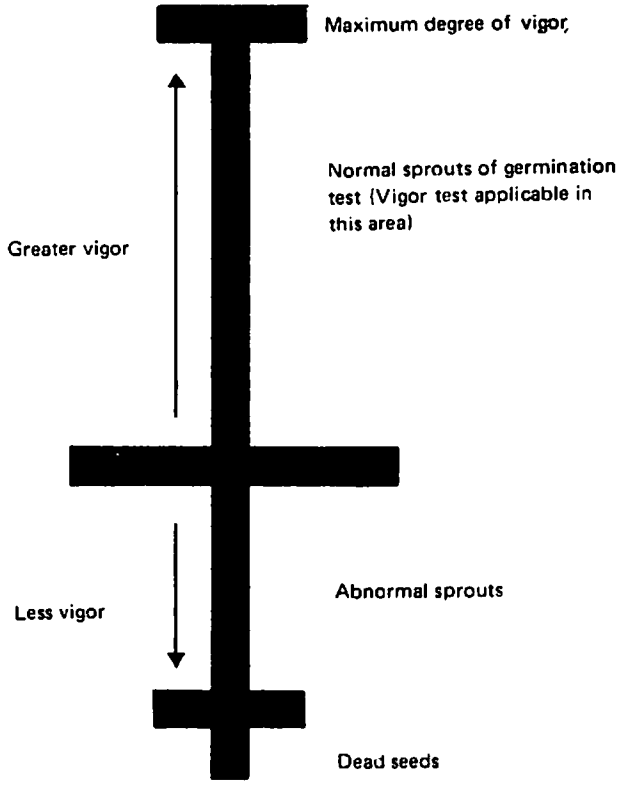

Fig. 1. Schematic representation of relationship between germination and vigor (revised from Isley 1957).

Subsequently, vigor has been defined in other ways. The Association of Official Seed Analysts (Anon. 1975) defines it as follows: "Seed vigor is the sum total of all those properties in seed which, upon planting, result in rapid and uniform production of healthy seedlings under a wide range of environments including both favorable and stress conditions." Another definition is that of the

International Seed Testing Association: "Seed vigor is the sum total of those properties of the seed which determine the potential level of performance and activity of a non-dormant seed or seedlet during germination and seedling emergence."

It must be understood that vigor is not a single measurable property like germination viability, but rather a quantitative character, controlled by several factors that affect the germinating seed or subsequent seedling. Therefore, vigor tests were eventually developed that took into consideration one or more seed/seedling attributes manifesting vigor.

A vigor test cannot replace a germination test but rather supplements it with more information about seed quality. A number of vigor tests proposed by different workers include those listed in Table 1, some of which are described in detail in this chapter.

Table 1. Various tests for seed vigor.

Type of test			
Physical	Performance	Stress	Biochemical
Seed size	First count	Cold test	Glutamic acid decarboxylase activity (GADA test)
Physical soundness	Speed of germination	Cool germination test	
	Coefficient of germination	Brick gravel test	Tetrazolium test
	Seedling growth rate	Paper piercing test	Respiration and RQ
	Seedling dry weight	Compacted soil	Mitochondrial activity
		Wet or dry soil	ATP level
		Pathogen infested soil	Membrane integrity
		Accelerated aging test	
		Low or high P	

Selected Tests for Vigor

1. *First count:* This test can be incorporated into the standard germination test. The number of normal seedlings removed when the preliminary count (first count) of the germination test is made is an indication of the seed lot's quality; the higher the percentage of normal seedlings removed at the preliminary count, the better the seed quality.

If the first count is to be used to compare different seed lots over several months, all first counts must be done at the same time interval after planting.

2. *Speed of germination:* If a more detailed test is desired, speed of germination may be used. This test can be incorporated into the standard germination test, but requires more time to evaluate than the standard germination test. After the seeds have begun to germinate, they must be checked at approximately the same time daily. Normal seedlings are removed from the test when they reach a predetermined size, until all seeds that are capable of producing a normal seedling have germinated. An index is computed for each seed lot by dividing the number of normal seedlings removed each day by the day after planting on which they were removed. Thus, quality indexes of lots A and B (15 and 20, respectively) are obtained in the following manner:

$$\text{Lot A} : \frac{\text{No. of seedling removed daily}}{\text{day after planting}} = \frac{0+0+0+8+10+24+28+24}{1\ 2\ 3\ 4\ 5\ 6\ 7\ 8}$$

$$= (0)+(0)+(0)+(2)+(2)+(4)+(4)+(3) = 15$$

$$\text{Lot B} : \frac{\text{No. of seedling removed daily}}{\text{day after planting}} = \frac{0+0+12+24+45+7}{1\ 2\ 3\ 4\ 5\ 6}$$

$$= (0)+(0)+(4)+(6)+(9)+(1) = 20$$

Lot B would be considered the better quality of the two lots since the higher index indicates better seed quality.

Lot B, with a higher index, would be considered the better quality lot.

3. *Seedling growth rate and seedling dry weight:* Total seedling growth in the greenhouse, field, or laboratory may be measured at a specific number of days after planting. The seed lot producing the most growth per normal seedling is considered the best quality. Seedlings may be cut, dried at 110°C for 17 hrs, and weighed for additional information. Better quality seed is considered to produce heavier seedlings.

4. *Cool germination test (for cotton):* This test may be conducted by using any type of germination equipment capable of maintaining a constant 18°C temperature and sufficient humidity to prevent drying of the substrata. It requires only one count, done on the sixth day for acid-delinted cottonseed and on the seventh day for machine-delinted cottonseed.

This type of test is limited to measuring the effect of cool temperature on the germination of cottonseed and the growth rate of cotton seedlings. This test differs from the cold test (a pathological test) in that it is a cool germination test conducted at a constant temperature of 18°C.

5. *Cold test (for corn):* The cold test is the oldest routinely-used vigor test. It was developed for corn seed but is equally useful for cotton, sorghum, and soybean seed evaluations. However, procedures and interpretation should be more standardized. This test is most useful to estimate field performance of seed in low temperature soil conditions.

The test is performed by planting seed in unsterilized soil obtained from a cornfield. A cold test should use at least four replicates of 50 seeds each. In general, the planting procedure is to place a 3/4" (about 2 cm) thick, levelled soil layer on the bottom of a plastic box. The seeds are distributed on the soil with a piece of wood cut to fit the box. Approximately the same amount of soil is then placed atop the seeds, levelled, and compacted. Enough water is added to bring the medium to 70% of its water holding capacity. This water should be brought to 10°C beforehand. After adding water, the boxes are covered and put into a refrigerator at 10°C. After seven days, the boxes are transferred to another chamber at 25°C. Seedling counts and/or measurements are made four days after transfer.

The results of cold tests are usually expressed as percentage germination: that is, the percentage of seedling-producing seeds that would be considered normal in a standard germination test. Additional information can be obtained from cold tests by making daily counts of emerged seedlings or by measuring comparative seedling heights.

6. *Brick gravel test:* This test was developed in Germany by Hiltner in 1911 to show pathogenic infection.

The method uses rather porous brick gravel of 2-3 mm diameter. In vigor tests on small grain, a layer of moist gravel about 1 1/5" (2.5 cm) thick is placed above the seed, which impedes the emergence of weak, partially diseased, corkscrew-type seedlings and other seedlings with injured coleoptile tips. Minor differences exist between the testing procedures at various laboratories, but the principles are about the same. The interwedging of the brick gravel places a stress upon the emergence of elongating shoots. The seedlings that emerge through the layer of brick gravel are traditionally considered strong. In 1955, German laboratories were requested to use the brick gravel value to separate the results from other types of vigor tests.

7. *Paper piercing test:* This method utilizes regular testing sand plus a special type of paper disc which seedlings must penetrate to be considered strong. The quality of paper selected provides results comparable to those from a test under favorable soil conditions. The test is especially suitable for small grains.

The paper must have the following characteristics: basic weight: 90 gm/mt^2, thickness: 0.4 mm, bulk: 4, dry bursting strength: 0.3 kg/cm^2, breaking length: 1000-5000 mm, filtering speed: 500 ml/min, wet bursting strength: 150 mm, ash content: 0.1%, fiber composition: chemical wood pulp with high alpha percentage.

The test as used for cereal crops requires placing seed on top of approximately 1/2" (about 1.2 cm) of moist sand, covering seeds with a special dry filter paper, and covering the paper with about 1 1/4" (about 3 cm) of moist sand. Tests are done at 20°C for eight days.

8. *Accelerated aging test:* This test was developed at the Seed Technology Laboratory, Mississippi State University, USA for different kinds of seed. This technique requires exposing seed to 40-45°C temperature and 100% relative humidity for two to eight days, followed by a regular germination test. Seed lots that maintain good germination even after accelerated aging also maintain it under normal storage conditions. On the other hand, lots with severely reduced germination after accelerated aging treatment decline rapidly in germination during storage.

The basic assumption of this test is that the germination percentage of a seed lot after a period of accelerated aging is highly related to the lot's vigor and hence to its capacity to perform well under field conditions.

9. *GADA test:* The glutamic acid decarboxylase activity (GADA) test measures the activity of one specific enzyme rather than a system of enzymes as in the tetrazolium test. The level of enzyme activity is determined by the amount of carbon dioxide (CO_2) given off and is positively correlated to seed quality; i.e., the more CO_2 given off, the better the seed quality (Grabe 1965). The relatively inexpensive equipment needed for this test consists of a water bath for controlling temperature; simple, easy-to-make manometers; a scale for measuring manometer fluid movement; small containers such as half pint jars; and a small grinder. Although the GADA test has given valuable results for corn and wheat, it has not proven as valuable for all seeds.

10. *Tetrazolium test (TZ):* The TZ test is used more and more widely to rapidly determine the viability of seed lots. It is used less often to evaluate vigor, which is unfortunate, because it provides the most accurate and useful information of any test on the physiological quality of seed. Admittedly, the information generated by the test is useful only to an experienced TZ analyst, but this should not impede wider use of the test.

The TZ vigor test involves the identification, location, and appraisal of sound, weak, and dead embryo tissues for their possible influence upon seed storage qualities, seed germination, and early seedling development under unfavorable as well as favorable conditions. The degree of soundness of different areas of embryonic tissues is made visible by use of a colorless, mainly aqueous solution of tetrazolium salt. The chemical 2,3,5-triphenyl tetrazolium chloride is used as the indicator. Differences in color, or lack of color, along with observation of tissue turgidity or flaccidness, permit recognition of sound, weak, and dead tissues. Simultaneous observations of the presence, location, and extent of fractures, missing embryo parts, insect cavities, and other abnormalities provide supplemental information essential for evaluating embryo soundness.

The soundness of embryos of individual seeds is appraised largely on the presence, amount, and depth of essential embryo structures. Comparative TZ, storage germination, and seedling tests are helpful to analysts who are learning to recognize and establish a general relationship between embryo observations and performance of seed and resulting seedlings under favorable conditions.

The TZ vigor test permits the simultaneous establishment of different levels of soundness. The simplest and accepted classification is to divide viable seeds into sound and unsound classes. Seeds with minor imperfections are considered sound.

11. *Respiration and R.Q.:* Respiration--especially during early hours of imbibition in water--has been shown to be closely correlated with seedling growth rate of lima bean, corn, wheat, soybean, and paddy. In corn and paddy, differences in respiration rate have been used to distinguish between high, medium, and low vigor seeds. However, in the case of paddy, intravarietal differences were obtained.

During the process of respiration, oxygen is taken up by seeds and carbon dioxide is evolved. The ratio of the volume of carbon dioxide evolved per unit time to the volume of oxygen consumed per unit time is called respiratory quotient (R.Q.)

$$(R.Q. = \frac{QCO_2}{QO_2})$$

The respiratory quotients were found to be more often related to the vigor than was oxygen uptake alone. The rate of gas exchange is measured in the Warburg respirometer.

The measurement of respiration has never been used routinely in seed testing laboratories, perhaps because expensive equipment is required.

12. *Membrane integrity (measurement of leachates):* As seeds age, the seed membrane becomes more permeable, so many substances in seeds such as sugars, free amino acids, organic acids, and various elements leach out in the presence of water. The concentration of leachates is normally measured either by the electrical conductivity method or by chemical methods. The author (1977), while working on paddy, observed that leaching of sugars is related to the total soluble sugars present in seeds. Temperature was also found to have a pronounced effect on leaching. With a temperature increase from 10°C to 40°C, a 122-153% increase in leaching was observed in paddy seeds, showing that while performing experiments on leaching, temperature should be carefully maintained. It should also be noted that leaching of sugars has not always been found to be related to vigor in crop seeds.

Concluding Remarks

Of all the tests described for evaluating seed vigor, not a single one has proven successful for all kinds of seeds. At one stage, the GADA test was very popular in the USA, but for various reasons it has lost popularity. If a vigor test must be used by a seed analyst in a seed testing laboratory, it should be inexpensive, rapid, easy to perform, and reproducible. Seed analysts the world over have been reluctant to use an elaborate method involving sophisticated equipment. No single test will satisfy all requirements and a method or combination of methods should be chosen to suit the seed type and sowing environment.

Of the various tests described, first count, speed of germination, seedling growth rate, seedling dry weight, cold test, cool germination test, accelerated aging test, tetrazolium test, and membrane integrity test are used most often to test vigor of various crop seeds in seed testing laboratories.

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Transmission of Seed-Borne Diseases and Important Seed-Borne Diseases of Wheat and Barley

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Seed used for propagation should be healthy and disease-free. Diseased seed is less viable, has low germination capacity and reduced vigor, and may show some morphological changes. In addition, diseased seed may have toxic effects on humans and animals.

Seeds in general are vehicles for the distribution and dissemination of plant pathogens and new pathotypes. Seed-borne pathogens are sometimes the cause of disease outbreaks, since small amounts of seed-borne inoculum can be of great epidemiological significance.

Seed-transmitted pathogens include bacteria, fungi, nematodes, and viruses. Most seed-transmitted pathogens are fungi. Seeds of the flowering parasitic plants (*Cuscuta* spp.) can also be transmitted by seed (Masri *et al.* 1983). Pathogens not transmitted by seed are mycoplasma-like organisms (MLO), rickettsia-like organisms (RLO), and the phloem-limited viruses (Neergaard 1977; Nienhaus and Sikora 1979).

Mode of transmission

Pathogens can be transmitted with the seed in three ways (Table 1), as follows:

Seed contaminants: Inert materials such as soil clods, plant debris, and/or loose reproductive organs of the pathogens might act as carriers of the active or resting stages of organisms. Important pathogen organs which can be carried with seed are fruiting bodies, telio- and uredospores, nematode galls, chlamydospores, and sclerotia.

Table 1. Mode of transmission of seed-borne pathogens.*

	Seed contaminants	Seed contamination	Seed infection
Contaminants/ Contamination/ Infection	soil clods, plant debris, loose reproductive organs	surface-borne (on seed coat/ pericarp)	embryo, endosperm, seed coat/pericarp
Pathogen organs	pycnidia, fruiting bodies, telio-urediospores, chlamydospores, nematode galls, sclerotia	oospores and spores, fruiting bodies, pycnidia, micro-sclerotia (virus particles, bacterial cells)	dormant mycelium, fruiting bodies, microsclerotia, virus particles, bacterial cells
Pathogen	nematodes, sclerotia-forming fungi, rusts	covered smuts, downy mildew, powdery mildews, wilt pathogens (viruses and bacteria)	viruses, bacteria, loose smut, nematodes

*Modified after Neergaard (1977).

Contamination of the seed surface: The seed coat and/or pericarp can carry different pathogen organs. Different kinds of spores, fruiting bodies, and microsclerotia are carried on seed surfaces. Even some viruses and bacteria can be transmitted this way.

Seed infection: Infection may occur in the embryo (embryal infection), in the endosperm, and on the seed coat (extra-embryal infection). Most seed-borne viruses and all loose smut pathogens fall into this category of transmission. Pathogen organs found in infected seed are dormant mycelium, chlamydospores, fruiting bodies, virus particles, bacterial cells, nematode larvae, and microsclerotia.

Seed-Transmitted Pathogens

Table 2 shows some legume and cereal pathogens that can be transmitted by seed. Species of the three bacteria genera *Corynebacterium*, *Pseudomonas*, and *Xanthomonas* are seed-borne and can be transmitted by seed. At least eight viruses and a large number of fungus species are also transmitted by legume seeds.

Seeds infected by *Ascochyta* spp. have lesions; the mycelium is usually located beneath the seed coat. In some seeds the mycelium penetrates even deeper (Halfon-Meiri 1970). *A. fabae* has little chance of infecting field bean crops from plant debris or volunteer seedlings; infected seed is the usual source of attack (Hewett 1983).

Pea seeds can be attacked by *Erysiphe pisi* (grey-brown seeds). This seed-borne disease became a limiting factor for pea production in some areas of the world through seed transmission (Blumer 1967; Dixon 1978). *Peronospora vicia* was introduced into Italy with imported pea seed (Ciccarone 1952, cited in Neergaard 1977) and is also found in vetch seeds.

Sclerotinia spp. are very serious pathogens and may accompany seeds as easily detectable sclerotia, or as mycelial infection. *Verticillium alboatrum*, which attacks species of *Medicago* and *Trifolium*, is a serious parasite in alkaline soils and a major wilt disease. Seed transmission of this pathogen is usually underestimated. Of the stem nematode *Ditylenchus dipsaci*, both races (oat race and giant race) are known to be seed-borne; the introduction and dispersal of *D. dipsaci* with faba bean seed is a real threat (Hooper 1980).

In cereals, several species of the three bacteria genera are transmitted by seed. Barley stripe mosaic virus is seed-borne. *Helminthosporium* spp. can cause infections that are mainly systemic, and *Drechslera victoria* in *Triticum aestivum* should be regarded as an

Table 2. Seed-borne pathogens of legumes and cereals.

Alfalfa, chickpea, faba beans, lentils, medics, vetches			
Bacteria	Viruses	Fungi	Nematodes
Corynebacterium sp.	Alfalfa MV	Ascochyta spp.	Criconemoides sp.
Pseudomonas fabae	BYMV	Botrytis spp.	Ditylenchus dipsaci
Xanthomonas spp.	BBMV	Cerospora zebrina	Helicotylenchus spp.
	BBMMV	Cladosporium spp.	Heterodera goettingiana
	PSBMV	Erysiphe pisi	
	Pea early browning virus	Fusarium spp.	
	Pea mild mosaic	Mycosphaerella pinodes	
		Peronospora viciae	
		Phoma medicaginis	
		Pleospora herbarium	
		Rhizoctonia solani	
		Sclerotinia spp.	
		Septoria pisi	
		Sclerotium rolfsii	
		Stemphylium sarciniforme	
		Verticillium albo-atrum	
		Uromyces fabae	
Barley and Wheat			
Corynebacterium spp.	Barley stripe mosaic virus	Alternaria spp.	Anguina tritici
Pseudomonas spp.		Claviceps purpurea	Criconemoides sp.
Xanthomonas spp.		Helminthosporium spp.	Haplolaimus spp.
		Fusarium spp.	Helicotylenchus sp.
		Rhynchosporium secalis	Protylenchus spp.
		Septoria spp.	Tylenchorhynchus spp.
		Sclerotinia spp.	
		Tilletia spp.	
		Urocystis agropyri	
		Ustilago spp.	

important threat for quarantine for many developing countries (Neergaard 1977). *Rynchosporium secalis*, though found in seed of barley, is carried predominantly in infected plant debris. *Anguina tritici*, the seed gall nematode, is dispersed principally by seed galls mixed with grain; larvae may be carried by seed of relatively normal appearance. *Helminthosporium* spp., *R. secalis*, *Ustilago* spp., and *Tilletia* spp. are the most important seed-borne diseases of cereals. All other nematodes of legumes and cereals mentioned in Table 2 are transmitted as seed contaminants (NBPGR 1980).

Important Seed-Borne Diseases of Wheat and Barley

Wheat

Common bunt (*Tilletia caries* and *T. foetida*)

1. At emergence the ears look normal, but the symptoms become apparent when the ears become older. Infected ears have a loose, open appearance, and the bunt balls are fatter than in healthy ears. The pericarp of the infected grains remains intact. Rupture of the grains reveals the dark teliospores and a strong unpleasant odor will be noticed.

2. Disease cycle: The fungus survives as teliospores on the kernel. Teliospores can over-summer two growing seasons in the soil, providing that the soil remains dry; in wet soil, the teliospores stay alive only a few weeks. Seedlings are only susceptible to the disease until the coleoptile splits (about 10 days at 12°C). The fungus grows with the plant and can reach the tissues just below the growing point. The mycelium infects the kernels, and mycelium cells are transformed into teliospores. Through threshing, spores are dispersed over healthy kernels and in the soil.

3. Prevention:

- Resistant cultivars can be used, although in the past the resistance of some cultivars broke down.
- Clean seed through field inspection.
- Sowing date: by sowing in early autumn, the young seedling passes through the susceptible stage faster.
- Chemical control: organo-mercury fungicides have been used in the past, but are now being replaced by more modern systemic types.

Loose smut (*Ustilago tritici*)

1. Loose smut symptoms are obvious between heading and maturity. Initially, diseased heads are black and clearly visible among newly-emerged, green, healthy heads. The infected heads emerge slightly earlier; later, the whole head is transformed into a dry mass of olive-black spores. The teliospores are held by a thin membrane; after it breaks, the spores are released and only the rachis of the kernel remains.

2. Disease cycle: The infection of the heads is only possible during a few days following fertilization of the flowers. Since the diseased heads emerge earlier, the release of the spores is synchronized with the susceptible period of the plant. The teliospores germinate on the flowers. Mycelium invades part of the seed embryo, thus the fungus survives as mycelium inside the seed. This makes chemical control complicated compared to control of common bunt fungi which remain on the seed surface. The infection of the young seedling occurs intracellularly out of the seed, and the fungus follows the growth of the plant intracellularly.

3. Prevention:
- Resistant cultivars: Resistance can be based on different mechanisms. The adult plant may possess resistance to the infection of the flowers by the teliospores, or the embryo may be resistant. Another possibility is selection for closed flowering. The plant then has a good chance of escaping infection.
- Clean seed through field inspection.
- Seed certification: Presence of the fungus can be detected by microscope.
- Chemical control: Only systemic fungicides are effective and have replaced the heat treatment, which is complicated and has a high risk of damaging the seed.

Barley

Covered smut (Ustilago hordei)

1. Infected heads emerge at about the same time as normal healthy ones. The black teliospores are usually retained within the persistent membrane of the grain.

2. Disease cycle: The teliospores survive on the grain under the hull. The infection cycle is more or less comparable to that of *Tilletia caries* on wheat; the seedling is only susceptible until the first green leaves appear. The mycelium advances intercellularly through the parenchyma until it penetrates the flower primordia. Healthy kernels are usually contaminated during threshing.

3. Prevention:

- Resistance breeding is possible.
- Chemical control can be done with contact fungicides although systemics are better.

Loose smut (*Ustilago nuda*)

1. The smutted head is surrounded by a very thin membrane which breaks down soon after head emergence. The olive-brown teliospores are then released and the heads can be reduced to a nude rachis.

2. Disease cycle: Like *Ustilago tritici* on wheat, this pathogen survives as mycelium in the embryo. Healthy plants are infected during flowering.

3. Prevention: Resistant cultivars, heat treatment, or chemical control with systemic fungicides can all prevent this disease.

Stripe disease (*Pyrenophora graminea* **syn.** *Helminthosporium gramineum*)

1. First symptoms are long, pale green stripes that may extend the entire length of the leaf. They can appear on the first leaf but usually do not appear until the four-to-five leaf stage. The stripes later turn greyish yellow and leaves can split along the stripes. Affected plants are often only half the size of the normal ones; most do not reach the stage of earing.

2. Disease cycle: The pathogen survives as mycelium inside the grain but outside the embryo. During seed germination, the fungus grows into the young plant and penetrates further up. Conidia develop on the killed tissues and spread to the healthy flowers where they germinate, generally near the awn end of the glume, giving rise to mycelium growth between glume and pericarp. Humid conditions in the heading period favor the infection of the kernels.

3. Prevention:
- Resistance breeding is possible.
- Use of certified seed.
- Hot water treatment or systemic fungicides.

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Control of Seed-Borne Diseases of Chickpea and Lentil

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Chickpea

Introduction

Of about 50 pathogens infecting chickpea (*Cicer arietinum* L.), six are of major importance (Nene 1980). These pathogens, including fungi, bacteria, viruses, mycoplasmas, nematodes, and parasitic weeds, reduce crop yield and affect the stability of chickpea production. At present, these pathogens are also the major impediment in realizing the potential yield of chickpea. The average yield of chickpeas--about 700 kg/ha--is very low, but yield levels of about 1500 kg/ha are obtainable with some minimum inputs of nitrogen, phosphorus, and irrigation, and with better management. The susceptibility of the present cultivars to a large number of diseases, however, and the risk of losing the entire crop through sudden disease development do not encourage farmers to apply inputs to the crop. Disease control is therefore essential both to increase and stabilize chickpea production.

Seed-Borne Diseases

Production and use of healthy seed for sowing is essential to obtain a good crop, especially for chickpea whose major diseases are seed-borne (Luthra and Bedi 1932; Haware *et al.* 1978; Cother 1977; Gurha *et al* 1982). These diseases are ascochyta blight (*Ascochyta*

rabiei (Lab.) Pass.), wilt (*Fusarium oxysporum* f. sp.*ciceri*), gray mold (*Botrytis cinerea*), and alternaria blight (*Alternaria circinum*). The presence of physiologic races in *A. rabiei* and *F. oxysporum* necessitates strict control on the exchange of seeds.

In addition to these major seed-borne diseases, several other fungi, some of which cause minor foliar diseases, root rots, seed rots, and seed decay have been reported as associated with chickpea seed. Mitra (1935) from Bihar state of India reported that the fungus *Mystrosporium* caused a new blight disease to be seed-borne. Zachos (1952) reported 27% of seed in Crete to be attacked and prevented from germinating by *Pleospora herbarum* (*Stemphylium botroysum*). *Alternaria* sp. and *Mycogone* sp. were recorded on stored seed from India (Anon. 1954). Das and Sengupta (1961) from West Bengal, India reported *Stemphylium sarchiniforme* causing leaf spot of chickpea to be seed-borne.

Westerlund *et al.* (1974) reported *Fusarium solani* f. sp. *pisi* causing root rot of chickpea to be seed-borne. Shukla and Bhargava (1977) also reported *F. solani* to be associated with chickpea seed. Mengista and Sinclair (1979) reported 15 fungi and a bacterium, *Bacillus subtilis*, in seed from Ethiopia.

Deo and Gupta (1980) reported 34 fungi belonging to 18 genera on stored seed, including nine species of *Aspergillus* (the four most common being *A. candidus*, *A. flavus*, *A. stellatus*, and *A. tamarii*); five species of *Penicillium* (*P. chrustosum*, *P. chrysogenum*, *P. islandicum*, *P. lividium*, and *P. simplicissinum*); and three species of *Alternaria* (*A. alternata*, *A. humicola*, and one unidentified). Three species of *Fusarium* (*F. equiseti*, *F. fusarioides*, and *F. moniliforme*) appeared quite frequently, while *Acremonium percisinum*, *Chaetomium globosum*, *Cladosporium tenuissinum*, *Cunninghamella* sp., *Curvularia lunata*, *Drechslera halodes*, *Gliocladium roseum*, *Monillia* sp., *Paecilomyces variotii*, and *Ulocladium chartarum* were sporadic. *A. flavus* showed the greatest incidence and *A. percisinum* the lowest. D'Ercole and Sportelli (1982) from Italy recorded *A. solani*, *F. moniliforme*, *F. roseum*, *F. oxysporum*, *Penicillium* spp., *Cladosporium herbarum*, and *Rhizopus nigricans* more often than *Botrytis cinerea*, *Mycosphaerella* spp., *Ascochyta* spp., and *Acremonium* from surface-sterilized seed.

At ICRISAT, *Alternaria* spp., *Ascochyta rabiei*, *Aspergillus* spp., *Botrytis cinerea*, *Curvularia* sp., *Fusarium* spp., *F. oxysporum*, *Penicillium* spp., *Phoma sorghina*, *Rhizoctonia bataticola*, and *Rhizopus* sp. were isolated from unsterilized seed. From surface-sterilized seed, *A. rabiei*, *Alternaria* sp., *B. cinerea*, and *F. oxysporum* were isolated. At ICARDA, *Ascochyta rabiei*, *Penicillium* spp., *Cladosporium* sp., *Rhizopus* sp., and an unidentified bacterium have been detected in blotter tests.

Control of Seed-Borne Diseases

Control of seed-borne diseases in chickpea is essential, since seed-borne fungi such as *Ascochyta rabiei* and *Botrytis cinerea* in extremely low amounts can cause severe disease epiphytotics under favorable conditions, resulting in complete crop loss. To minimize the role of seed-borne fungi, healthy seed should be produced for sowing purposes, resistant varieties should be developed and cultivated, and fungicidal seed-dressing should be used to eradicate seed-borne fungi (Table 1). The combined use of the three methods is necessary in many situations.

Table 1. Seed-borne diseases/mycoflora of chickpea and their control.

Disease	Causal organism	Recommended seed-dressing	References
Ascochyta blight	Ascochyta rabiei	Calixin M 3 g/kg/ Calixin M + Benlate (1:1) 3 g/kg/ Thiabendazole 3 g/kg	Reddy 1980, Reddy 1984
Wilt	Fusarium oxysporum f. sp. ciceri	Benlate T (benomyl 30% + thiram 30%) 2.5 g/kg	Haware et al. 1978
Gray mold	Botrytis cinerea	Bavistin 25% + TMTD 50% 2.5 g/kg	Grewal 1982
Mystrosporium	Mystrosporium sp.	Formalin 0.5%	McRae 1932
Pre- and post-emergence rot	Seed mycoflora	Agroson G N Agallol, Captan, thiram	Suhag 1973
Storage fungi	34 fungi belonging to 18 genera	Ceresan, Dithane 7-78, calcium propionate, sorbic acid	Deo and Gupta 1983

Ascochyta blight

Since seed-borne inoculum of *A. rabiei* is the most important primary source of inoculum for blight development, a number of studies have been conducted to identify a suitable fungicidal seed dressing for eradicating the fungus from infected seed.

Sattar (1933) suggested use of clean seed, disinfection of seed in 0.5% copper sulphate solution for 10 minutes, and treating internally-infected seed by pre-soaking in water at 20°C for 6 hrs and

then dipping it into hot water at 53°C for 15 minutes. Zachos (1951) reported that dipping surface-sterilized infected seed in 0.005% malachite green for 2 hrs, 0.05% formalin for 4 hrs, and hot water at 45-47°C for 10 minutes gave 84, 93.3, and 87.5% control, respectively. Khachatryan (1961) found seed treatments with thiram and 50% T.S.E. at 5 and 10 kg/ton most effective. Ibragimov *et al.* (1966) reported that use of phenthiuram (40% thiram, 10% Cu trichlor-phenolate, and 20% Y-BHC) and phenthiuram molybdate at 3-4 g/kg controlled blight infection. Karahan (1968) reported best results by treatment with Arasan-75 at 300 g/100 kg seed.

Kaiser *et al.* (1973) reported that seed treatment with benomyl and TBZ greatly reduced seeding infection. Seed dressing with Calixin M (11% tridemorph and 36% maneb) (3 g/kg), mixture of Benlate and Calixin M (1:1) (3 g/kg), and thiabendazole (Tecto 60) (3 g/kg) almost completely eradicated *A. rabiei* from deeply infected seed (Reddy 1980; Reddy *et al.* 1982; Reddy 1984).

Foliar spraying of chlorothalonil (Bravo 500) at intervals of 10-15 days produced healthy seed even from a highly susceptible cultivar under favorable conditions for blight development. Lines with high levels of resistance to blight with no pod and seed infection are identified, and use of such lines in the development of blight resistant cultivars could greatly reduce the problem of seed infection with *A. rabiei* (Reddy 1983).

Wilt

Seed treatment with Benlate-T (benomyl 30% + thiram 30%) at the rate of 2.5 g/kg seed was found to eradicate internally seed-borne *Fusarium oxysporum* f. sp. *ciceri*. It remained effective for at least one year after treatment (Haware *et al.* 1978; Haware and Nene 1981).

Gray mold

Grewal (1982) reported that seed dressing with a combination of Bavistin 25% + TMTD 50% showed a synergistic effect and controlled internal and external seed infections of *A. rabiei* and *Botrytis cinerea*.

Other seed-borne fungi

The above fungicides recommended for ascochyta blight, wilt, and gray mold also eradicate most other seed-borne fungi. Some of the fungicides found specifically effective for eradicating storage fungi are also reported.

McRae (1932) reported that seed disinfection with 0.5% formalin killed the spores of *Mystrosporium* leaf blight. Suhag (1973) obtained best control of mycoflora of gram causing pre- and post-emergence rot by treating the seed with Agroson G N, Agallol, Captan, and Thiram. Deo and Gupta (1983) reported that seeds treated with Ceresan, Dithane 7-78, calcium propionate, and sorbic acid considerably decreased the incidence of storage fungi and maintained good germination.

Lentil

Introduction

Lentil suffers from diseases caused by fungi, bacteria, viruses, nematodes, and phanerogamic plant parasites. The important ones are wilt (*Fusarium oxysporum* f. sp. *lentis*), rust (*Uromyces fabae-lentis*), ascochyta blight (*Ascochyta lentis*), botrytis blight (*Botrytis cinerea*), downy mildew (*Peronospora lentis*), powdery mildew (*Erysiphe polygoni*), alternaria blight (*Alternaria tenuis*), stem rot-blight (*Sclerotinia sclerotiorum*), collar rot (*Sclerotium rolfsii*), root rot (*Rhizoctonia bataticola, F. solani, F. roseum, Pythium ultirum, P. debaryarnum*), viruses (bean yellow mosaic, pea leaf-roll virus, alfalfa mosaic, cucumber mosaic, pea mosaic), and nematodes (root-knot: *Meloidogyne* sp., cystnematode: *Heterodera* sp.).

Seed-Borne Diseases

The important diseases reported to be seed-borne are wilt, ascochyta blight, botrytis blight, alternaria blight, and pea mosaic virus. The other fungi reported to be associated with lentil seed and causing root rot and seed rot are *Penicillium* spp., *Fusarium moniliforme, F. semitectum, F. equiseti, F. solani, F. roseum, Rhizoctonia bataticola, Aspergillus flavus, A. niger, A. ochraceous*, and *Sclerotium rolfsii*. The other storage fungi found to be associated with the seed are *Alternaria alternata, A. tenuissima, Fulvia fulva, Curvularia lunata, Helminthosporium* sp., *Chaetomium* sp., *Thanatephorus cucumeris, Phoma* spp., and *Stachybotrys* sp.

The sclerotia of *S. sclerotiorum* and plant parts infected with *Uromyces fabae* (rust) and *Peronospora lentis* (downy mildew) become mixed with seed and cause contamination.

Control of Seed-Borne Diseases (Table 2)

For wilt, seed treatment with thiram + brassicol or thiram + Bavistin (1:1) at the rate of 2.5 g/kg seed, Benlate (0.3% by weight), 0.15% boric acid and $KMNO_4$ considerably reduced disease incidence.

For stem rot/blight (*S. sclerotiorum*), seed-dressing with thiram or Phaltant (0.2% by weight) has reportedly provided effective control.

Table 2. Seed-borne diseases/mycoflora of lentil and their control.

Disease	Causal organism	Recommended seed dressing
Wilt	Fusarium oxysporum f. sp. lentis	Thiram + brassicol or thiram + Bavistin (1:1) 2.5 g/kg Benlate 0.3% and 0.5% boric acid and $KMNO_4$
Stem rot/ blight	Sclerotinia sclerotiorum	Thiram or Phaltant 0.2%
Rust	Uromyces fabae-lentis	Organomercury fungicides
Ascochyta	Ascochyta lentis	Benomyl
Collar rot	Sclerotium rolfsii	Thiram + brassicol (1:1), 2.5 g/kg
Seed rots	Rhizoctonia, Sclerotium, Fusarium, Phoma	Vitavax and Benlate 0.2%
Root rot	R. solani	Agrosan 0.3%

For rust, use of seed that is free from rust-infected plant material is essential, since infected plant material can act as primary inoculum. Seed treatment with organomercury fungicides has been recommended to render the seed-borne inoculum ineffective.

For ascochyta blight, seed treatment with benomyl was found to effectively disinfect and protect the seeds. For collar rot caused by *Sclerotium rolfsii*, seed treatment with thiram + brassicol (1:1) at 2.5 g/kg seed has given promising results in the field.

Seed dressing with thiram, Captan, and Bavistin have been reported as very effective in controlling the seed mycoflora of lentil and improving yields.

A seed dressing of Vitavax followed by benlate at rates of 0.2% gave best control against *Rhizoctonia*, *Sclerotium*, *Fusarium*, and *Phoma*. Agrosan at a rate of 0.3% gave the best control against *R. solani*.

Seed Health Testing Procedures (Summarized from Neergaard 1977)

Different methods of seed health testing have been developed. Generalized tests may reveal a wide range of pathogens, while specialized tests detect a particular species, pathogenic race, or strain. Most commonly used generalized tests for detecting fungi are the ordinary (standard) blotter test and agar plate test, which reveal a wide range of fungi, although they are largely restricted to the Fungi Imperfecti. The other very versatile testing procedures are seedling symptom tests and growing-on tests. The specialized tests are serological, used for detecting and identifying different viruses, bacteria, or strains of each; phage-plaque tests used for identifying bacterial strains; and indicator-plant tests used for identifying physiologic races of pathogens.

1. **Direct inspection:** Examination of impure dry seed using a hand lens or, preferably, a stereoscopic microscope. Seeds may be submerged in water drops to release spores and facilitate detection.
   Application: Sclerotia of fungi, smut ball, nematode galls, infected plant debris; e.g., *Sclerotinia sclerotiorum*, *Botrytis cinerea*, *Claviceps purpurea*. Seeds discolored or with lesions produced by fungi, bacteria, or viruses; e.g. *Xanthomonas phaseoli*, and viruses such as soybean mosaic virus in leguminous seed.

2. **Examination of suspension for washings of seed:** An electrical mechanical shaker can be used to obtain standardized washings.

Samples of the suspension are examined under a compound microscope. *Application*: Covered smut: e.g. *Ustilago hordei* and *Tilletia* spp. in cereals: oospores of certain downy mildews; quick detection of other fungi that must be adequately detected by incubation procedures: e.g., *Pyricularia oryzae*, *Drechslera oryzae*, and *Trichoconis padwickii* in rice.

3. **Whole embryo count method:** Soaking grains overnight in 10% NaOH at 22°C, then washing with warm water through sieves of decreasing mesh size. Embryos finally cleared in lactophenol.
   Application: Loose smuts of barley, *Ustilago nuda*, and wheat, *Ustilago tritici*.

4. **Blotter method:** Seeds are incubated on a water-moistened blotter, usually for seven days at 20°C. Sporulation of fungi is stimulated by near-ultraviolet (NUV) irradiation, standard 12/12 hr light/dark cycle. Petri dishes are usually used as containers. To allow NUV penetration, plastic or pyrex glass containers should be used. Sometimes blotters are soaked in 0.1-0.2% 2,4-D solution to counteract seed germination, thus aiding recording.
   Application: The method is used most commonly to detect a considerable range of Fungi Imperfecti, including different spp. of *Acremonium*, *Acroconidiella*, *Botrytis*, *Alternaria*, *Ascochyta*, *Cercospora*, *Collectotrichum*, *Diplodia*, *Drechslera*, *Fusarium*, *Macrophomina*, *Mytothecium*, *Phoma*, *Phomopsis*, *Septoria*, and others, and also for practically all kinds of seed, including cereals, grasses, ornamentals (flower seeds), forest seeds, and vegetables.

5. **Agar plate method:** The seeds are placed in petri dishes on nutrient agar, in particular malt extract agar (MA), and potato dextrose agar (PDA). Some selective media are available for specific tests. Light treatment is the same as for the blotter test, and incubation is for five-to-seven days. Experienced analysts can assess results by naked-eye examination, using colony characters as criteria.
   Application: This is the classical procedure for flax seed on MA (Ulster method), and used (on PDA) for detection of *Septoria nodorum* in wheat (Bronnimann's method, continuous daylight for seven days), for *Ascochyta* spp. on pea, and for other fungi and hosts. Although slow growing fungi cannot be adequately detected, the procedure is relatively sensitive for revealing minor amounts of inoculum.

6. **Freezing method:** A modified blotter method. After one-to-two days at 10-20°C, according to specification, incubation for some hours

or for one day at -20°C, then at 20°C NUV light for five-to-seven days.
Application: Sometimes preferred for detecting certain fungi; e.g., *Phoma lingam* in cruciferous seeds, *Septoria nodorum* in wheat, and *Alternaria porri* in onion.

7. **Ordinary seedling symptom test:** The seed is sown in autoclaved soil, sand, or similar material and placed under normal daylight conditions for observation of symptoms. A special procedure, the classical Hiltner test, offers standard conditions for detecting seedling pathogens.
Application: Often used for detecting seedling symptoms which reveal pathogens rather than fungi to be identified. Useful for detecting nursery pathogens of forests and detecting cereal seedling pathogens.

8. **Water agar seedling symptom test:** The seeds are sown on water agar in 16 mm test tubes, one seed per tube, or in microculture plastic plates or petri dishes. They are placed under daylight conditions; i.e., 12/12 hr cycle of artificial daylight and darkness. Seedlings are inspected for symptoms, and healthy seedlings may be transplanted for further post-quarantine cultivation.
Application: Can be used for many kinds of seed as an economical procedure which, in test tubes, allows separation of healthy and infected seedlings. Has been used for detecting *Drechslera graminea*, *D. sorokiniana*, and *D. teres* in barley; *Septoria nodorum* and *D. sorokiniana* in wheat; *Didymella bryoniae* in cucubit; *Macrophomina phaseaolina* in sesame; and other pathogens and hosts.

9. **Indicator test, inoculation methods:** A standard technique for identifying viruses but also used for detecting trace amounts of pathogenic bacteria; e.g., by hypodermal injection of indicator plants with material of the tested pathogen.
Application: Used for detection of *Xanthomonas phaseoli* and other bacteria in French bean, *Xanthomonas campestris* in crucifers, and possible use for detection of *X. oryzae* in rice, etc.

10. **Phage-plaque method:** Maceration of the seed to be tested after incubation for 24 hrs to enable multiplication of bacteria. Samples of this material are transferred to sterile flasks, and a standard suspension of phage particles is added. Samples of this mixture are plated immediately for 6-12 hrs on plates with the

indicator bacterium. Presence of homologous bacteria is indicated by significant increase in number of phage particles in the second plating.
Application: Used for detection of *Pseudomonas phaseolicola* and *Xanthomonas phaseoli* in French bean, *Pseudomonas pisi* in pea, and *Corynebacterium michiganense* and *Xanthomonas vesicatoria* in tomato. Used for routine testing of foundation seed of French bean in Canada.

11. **Serological methods:** An antiserum must be provided and the tests may follow different procedures: the slide agglutination test, the tube precipitin test, the micro-precipitin test, the gel double diffusion test, the latex flocculation test, and the immunofluorescence test.
Application: Used for different seed-borne viruses, and may be used for any pathogen for detection of *Pseudomonas phaseolicola.*

Methods for Detecting Seed-Borne Viruses

1. Visual examination of seed for externally visible seed abnormalities associated with virus infection, such as seed-coat mottling in soybeans due to soybean mosaic virus infection.
2. Growing-on tests in which seedlings produced are examined for symptoms. These tests, however, cannot detect viruses that are carried with no symptoms.
3. Infectivity test employing indicator plants that specifically react to certain viruses irrespective of symptoms in the tested material. When used along with growing-on tests, these provide additional information.
4. Serological tests overcome the shortcomings of the above tests and are direct, specific, and rapid.
5. Electron microscope tests.

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Seed Treatment

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Seed health is an important attribute of quality seed. A seed lot that meets high standards of germination, vigor, and purity, but is contaminated with seed-borne pathogens, may be useless for farmers, because it may result in severe yield losses or even crop loss in an entire area.

Seed may be affected by viruses, bacteria, fungi, nematodes, and insects. Seed pests and diseases of which the seed is a victim (e.g., grain weevils, *Trogoderma* spp., and storage pathogens such as *Aspergillus flavus*) should be distinguished from seed-borne diseases, of which the seed is the vehicle of pest and pathogen dissemination (e.g., bunt of cereals, *Tilletia* spp.)

Since the first group is easily detected and may destroy a seed lot, it is usually taken care of. Optimum storage conditions help in suppressing this group. For the second group, seed treatment is one means among others to achieve healthy seed. The other methods, mentioned only briefly in this context, include seed production in disease-free areas, seed production under effective disease control, and field inspection schemes.

Only certain groups of pathogens can be controlled effectively by seed treatment. There are good pesticides available to control fungal pathogens and insects; for viruses, bacteria and nematodes, there are still problems to be solved.

Seed treatment can be carried out through application of heat, mixing chemicals with seeds (seed dressing), and fumigation. Each treatment is described here in some detail.

Application of Heat

Heat can be applied using hot water or hot air, or as solar heat. Hot water, the most widely used, was first applied at the end of the 19th century to control cereal smuts. Until the introduction of systemic fungicides in the late 1960s, hot water treatment was the only way to control loose smut (*Ustilago nuda, U. tritici*). It is currently used by the Australian quarantine authorities to control exotic pathogens. The procedure for wheat is to presoak the seeds for 4-5 hours at 37-40°C, then treat them for 10 minutes at 54°C followed by air drying. Hot air is also sometimes applied to eradicate viruses from seed, and solar heat treatment is used in countries with hot climates such as Egypt, but is being replaced by chemical treatment.

Mixing of Chemicals with Seeds (Seed Dressing)

This is now a standard seed treatment procedure for many crops such as cereals, rapeseed, and cotton. The wide range of chemicals available is increasing. Equipment has been developed to ensure a safe, exact dosage.

Chemicals

Table 1 gives an overview of chemicals used for seed dressing. This list is certainly not complete, nor does it imply a recommendation of the chemicals listed over others. It should also be noted that chemicals may not be registered in some countries, or may be registered under different trade names.

Chemicals may be available in different formulations; e.g., dust, wettable powder for slurry treatment, or liquid concentrates. In general, dusts are applied at a rate of approximately 2 g/kg seed, and slurries or liquids at 5-10 ml/kg seed. The latter formulations are frequently preferred over dust, because they enable easier exact measurement, allow better coating of the seeds, and cause less hazard to operators by avoiding dustiness. Different admixtures may be used in dust treatment to avoid the last two problems. A cheap additive is a 0.2% dextrine solution, added at a rate of 3-5 ml/kg seed. More effective, but also more expensive, are special "incrusters;" e.g., Sacrust.

Selection of the proper chemicals depends on the target organisms. In general, we can distinguish between three types of pathogens:

Table 1. Some chemicals used for seed dressing.*
Important: Read the label before applying pesticides.
Follow instructions on the label.

Pest/Disease	Crop	Trade name/ Manufacturer	Active Ingredient(s)	Recommended Dosage
Host storage pests	all crops	Malathion/ American Cyanamid	malathion	10 ppm a.i.
		Dunfin/ Ciba Geigy	methacrifos	5-10 g a.i./ton
		Nuvan 7/ Ciba Geigy	dichlorvos 70 g/l	2-3 dl/ton
		Actellic/ ICI	pirimiphos-methyl	4-10 ppm a.i.
Wire worms, other soil insects	mainly sugar beets	Agronox/ Celamerck	lindan 20%	500-800 g/ 100 kg
Many soil insects, birds	corn, sugar beets	Mesurol/ Bayer	mercaptodimethur 80%	1 kg/100 kg
Xanthomonas malvacearum	cotton	Bronocot/ ICI	12% bronopol	1 kg/ 150-200 kg
Bacterial diseases	different crops	Copac E/ BASF	copper sulphate (30 g/l copper)	Under test
Tilletia spp. Septoria spp. Fusarium nivale	cereals	Quinolate 15/ Quino-la Quinoleine	15% copper oxiquinolate	200 g/100 kg or 200 g + 300-500 cc water/100 kg
Ustilago spp. Tilletia spp. Fusarium nivale	cereals	Campogran/ BASF	furmecyclox 500 g/l (liquid) 40% (powder)	250 ml/100 kg 250 g/100 kg
Rhizoctonia solani	cotton			
Helminthosporium spp. Fusarium spp. Septoria nodorum	cereals	Sportak Bejdse/FBC	200 g/l prochloraz	0.2-0.5 g a.i./kg
Gibberella fujikuroi Helminthosporium	rice	Sportak/ FBC	250 g/l prochloraz EC formulation	Seeds soaked 24 hours in solution of 17.5 g a.i.
Helminthosporium spp. Tilletia caries Fusarium spp. Septoria nodorum Ustilago nuda	cereals	Rovral ts/ Rhone-Poulence	35% iprodione 17.5% carbendazim	150 g/100 kg; for U. nuda increase rate to 200-250 g
Tilletia spp. Ustilago spp. Helminthosporium spp. Fusarium nivale	cereals	Arbosan UT/ Ciba Geigy	15% methfuroxam 2.5% imazalil 2.5 thiabendazole	200 g/100 kg
Tilletia spp. Urocystis spp. Fusarium nivale	wheat rye	Sibutol/ Bayer	37.5% bitertanol 2.3% fuberidazole	150 g/100 kg; for T. contraverso increase rate to 200 g
Tilletia spp. Urocystis spp. Ustilago spp. Helminthosporium spp.	cereals	Baytan/ Universal Bayer	22% triadimenol 3.3% imazalil 3% fuberidazole	150-200 g/ 100 kg

Tilletia spp. *Urocystis occulta* *Ustilago* spp. *Helminthosporium* spp.	cereals	Vitavax 200 and other formulations/ Uniroyal	17% carboxin 17% thiram	250 g/100 kg
Rhizoctonia spp. *Fusarium* spp. *Alternaria* spp. *Verticillium* spp. *Sclerotinia* spp.	pepper tomato cabbage cucumber	Rovral ts/ Rhone-Poulenc	35% iprodione 17.5% carbendazim	250-500 g/ 100 kg
Rhizoctonia solani	cotton	Derosal 60 WP/ Hoechst	59.4% carbendazim	180 g/ 100 kg
Colletotrichum lindemuthianum	beans	Derosal 60 WP/ Hoechst	59.4% carbendazim	300 g/100 kg
Ascochyta spp.	legumes	Calixin M/ BASF	11% tridemorph 36% maneb	300 g/100 kg
Damping-off diseases	legumes, other crops	Antiram/ Aagrunol-Stacher	67% thiram	300 g/100 kg

* Compiled from manufacturers' information brochures.

- Pathogens contaminating the seed superficially and infecting the seedling after planting; e.g., common bunt (*Tilletia* spp.) and flag smut (*Urocystis agropyri*). These are easy to control with a wide range of chemicals.
- Pathogens infecting the embryo during flowering; e.g., loose smut (*Ustilago* spp.). These can be controlled only with systemic fungicides.
- Pathogens infecting many parts of the plant (leaves, stems, pods, seeds); e.g., *Helminthosporium* spp. and *Ascochyta* spp. These are controlled with systemic fungicides.

The first two groups of pathogens have only one generation per year, and are exclusively seed-transmitted, while the third group can also be controlled with fungicide applied in the field.

For insects, control of storage pests is usually more effective with fumigation. In some cases, however, seed treatment may be preferable, especially to protect the seedling against soil insects.

Even with excellent chemicals available, it is difficult if not impossible to achieve 100% control. During the treatment process, some seeds almost always escape proper treatment, whereas others receive more than the recommended dosage.

Equipment

The simplest way to mix seed with chemicals is with a shovel. This method, however, does not meet the requirements of even mixing, avoiding under- and overdosage, and operator safety.

Better methods include using a concrete mixer or a hand- or motor-driven drum, preferably in a diagonal position. Care must be taken to ensure that these devices are operated long enough to distribute the chemicals evenly. A major disadvantage is that the dosage is measured by hand. More often than not, an unknown quantity of chemicals is added to an unknown quantity of seed, usually resulting in over-treated seed, which is not only quite expensive, but may also damage seed viability.

For these reasons, machines have been developed that ensure automatic measuring of chemicals. In the Gustafson treaters, for instance, the weight of the seed, measured in a weigh pan, is used to operate the chemical measuring system. By adjusting a counterweight, the same quantity of seed is treated with the same quantity of chemical, measured in standard cups and operated with the trip of the weigh pan. Sizes appropriate for the required treatment capacity are available for this device and for similar devices from other manufacturers.

All automatic seed treaters work reliably only when properly calibrated. The manufacturer's instructions should be followed.

Safety

There is a general tendency to use chemicals that are safe for user and environment. Very toxic substances, such as organic mercurials (Ceresan and others), and very persistant fungicides, such as Hexachlorobenzene (HCB), are being replaced by new chemicals. In the past, these chemicals have caused severe cases of poisoning, some resulting in death. Most if not all occured because treated seed was used for human consumption and/or livestock feeding instead of for planting. Even with the new, less toxic chemicals, the following safety precautions must be taken:

- Treated seed must be clearly labelled and under no circumstances be used for feed or food.
- Seed treatment should be carried out in a well-aerated area. Contact with chemicals through breathing of dusts and skin contact must be avoided. Protective clothing should be worn.
- As with all pesticides, empty containers should be properly disposed of and never reused in the household or on the farm.

Fumigation

In many countries, fumigation is a routine treatment, carried out mainly against storage insects (grain weevils, bruchids). In general,

the procedure is to apply a volatile insecticide in a confined area (silo, warehouse, or fumigation chamber). For effective fumigation, air-tight sealing is essential. The main advantage of fumigation is that all insect stages are controlled.

Chemicals

Two chemicals are widely used: phosphine and methyl bromide. Others are dichlorvos, carbon dioxide, ethylene oxide, and HCN.

Phosphine: Available in a solid form (0.6 g pellets, 3 g tablets). The active ingredient is aluminium phosphide, mixed with ammonium carbonate and paraffin (trade name: Phostoxin). After exposure to the atmosphere, the pellets decompose and release the active substance, hydrogen phosphide (PH_3), which has the same specific weight as air, and is thus evenly distributed in the fumigated material or chamber. Phosphine is also able to penetrate bags, carton boxes, and other containers.

The recommended dosage is 1/2 to 1 tablet/m^3, with an exposure time of 2-4 days for pellets and 3-5 days for tablets. Tablets or pellets are placed on cardboard, spaced sufficiently apart to prevent spontaneous ignition. The powdery residues can be removed.

The major advantages of Phostoxin are that it lacks residues, does not affect flavor or germination, and is easy to handle.

Methyl bromide: Above 5.6°C, methyl bromide is in the gas phase, and is available in cylinders similar to those used for cooking gas. Since it is odorless, other gases such as chloropicrin are sometimes added to facilitate detection of leaks. Because methyl bromide is 3.5 times heavier than air, care has to be taken that it is properly distributed within the goods to be fumigated (fan can be used). The recommended dosage is 20 g/m^3 for 24-48 hrs.

Special safety measures are required, since methyl bromide is absorbed through the skin. It tends to accumulate in commodities, which is important whenever repeated fumigation is necessary.

Equipment

Gas-proof plastic sheets with at least 50 cm overlap, firmly pressed to the ground with sand, iron bars, or other weights are frequently used. Gas escape results in reduced insecticidal effect and is a hazard to users. A cement floor is necessary to prevent gas escape through soil. Care must be taken that the fumigation area is properly aerated; fans sometimes help.

If a store's doors and windows can be hermetically sealed, fumigation of the entire store is possible. Most stores, however, allow gas to escape through other openings. Silos are usually good fumigation facilities. When large quantities must be fumigated within a short time, a vacuum fumigation chamber is appropriate. These chambers are available in sizes between 1 and 50 m^3, and sometimes as a plant of up to 6 x 50 m^3, equipped with common fans, pumps, and other equipment. The insecticides used are methyl bromide or ethylene oxide.

Safety

Face masks with a proper canister should be used, especially during the aeration process. When handling Phostoxin, cotton gloves should be worn. Gas concentration can be checked with a Halide gas detector for methyl bromide and with a tube detector (Draeger) for Phostoxin. A warning sign should be clearly visible to prevent people from inadvertently removing plastic sheets or entering a building under fumigation.

Appendix. List of manufacturers' addresses.

Aagrunol - Staehler
Postfach 2047
2160 Stade
West Germany

American Cyanamid
Berdan Avenue
Wayne, N.J. 07470
U.S.A.

BASF
6700 Ludwigshafen
West Germany

Bayer AG Pflanzenschutz
509 Leverkusen - Bayerwerk
West Germany

Celamerck
Binger Strasse
6507 Ingelheim
West Germany

Ciba Geigy
4002 Basle
Switzerland

FBC Limited
Hauxton, Cambridge
CB2 5HU
England

Hoechst AG
Postfach 80 03 20
6230 Frankfurt 80
West Germany

ICI
Plant Protection Division
Fernhurst, Hasslemere,
Surrey, GU27 3JE
England

Quino - la Quinoleine
43, rue de Liege
75008 Paris
France

Rhone-Poulenc
P.B. 9163
69263 Lyon Cedex 1
France

Seed Storage

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Quality seeds are the cheapest input in modern agriculture. Availability of viable and vigorous seeds at planting time is very important for increasing agricultural production, because good seeds act as a catalyst for realizing the potential of other inputs.

The loss of seed viability during storage cannot be stopped, nor can viability be increased during storage. Seed storage, however, should minimize the loss of seed viability and vigor.

There are three types of storage, of which the first two are discussed in this paper:

1. Storage of seeds from harvest to next planting (short duration, 6-8 months).
2. Storage of carryover seeds (medium-term, usually 12-14 months).
3. Storage of germplasm, breeder seed, samples tested in seed testing laboratories for regulatory purposes, etc. (long-term, usually 5-20 years).

Seeds can be divided into two majcr groups, orthodox and recalcitrant, according to their viability characteristics. The period of viability in orthodox seeds is increased with the decrease in seed moisture and storage temperature. Examples include seed of cereals, food legumes, and forages. Orthodox seeds of different species vary considerably in storage characteristics. They may be good (*Oryza sativa, Vigna radiata*); intermediate (*Gossypium* sp., *Sorghum bicolor, Triticum* sp.); or poor (*Glycine max, Arachis hypogea*).

Recalcitrant seeds, the second type, cannot be dried without harmful effects, and have a short viability period under ambient conditions. Examples include seeds of coffee, rubber, cocoa, and oil palm.

A number of factors influence the viability of seed during storage. The two most important are seed moisture, or relative humidity of the atmosphere, and storage temperature. Other factors include the storage temperature of the seed, inheritance, gas during storage, microflora and insects, and fungicides.

Relative Humidity

Relative humidity (RH) is a measure of water vapor in the air relative to the amount that air can hold at saturation at a given temperature. As air temperature increases, the water-holding capacity of air also increases. If the absolute weight of moisture remains constant, RH decreases upon heating. If the air is heated, the water-holding capacity of the air increases rapidly (Table 1).

Table 1. Moisture in air at saturation (100%) at different temperatures.

Temperature °C	Water vapor (g)/ dry air (kg)
-5	2.48
0	3.78
10	7.63
20	14.70
30	27.18
40	48.79
50	86.11

Each kind of seed will attain a characteristic moisture content at a given RH at a particular temperature, which is called the equilibrium moisture content (Table 2). Seeds of most species can be dried to 2-3% moisture without significant injury, provided injury is not caused by another factor associated with seed drying, such as high temperature.

Table 2. Seed moisture equilibrium at various levels of relative humidity at about 25 °C (wet weight basis).

Crop	Relative humidities						
	15	30	45	60	75	90	100
	Moisture content						
Barley (*Hordeum vulgare* L.)	6.0	8.4	10.0	12.1	14.4	19.5	26.5
Corn, field (*Zea mays* L.)	6.5	8.5	9.9	12.2	13.6	18.3	23.0
Cotton (*Gossypium hirsutum* L.)	-	6.0	7.5	9.1	11.5	18.0	-
Flax (*Linum usitatissiumum* L.)	-	5.6	6.3	7.9	10.0	15.2	21.4
Oat (*Avena sativa* L.)	5.7	8.0	9.6	11.8	13.8	19.5	24.1
Groundnut (*Arachis nypogaea* L.)	2.5	4.2	5.6	7.2	9.8	13.0	-
Rice (*Oryza sativa* L.)	6.8	8.6	10.7	12.6	14.4	18.4	23.6
Rye (*Secale cereale* L.)	7.0	8.7	10.5	12.2	14.8	20.6	26.7
Sorghum (*Sorghum bicolor* (L.) Moench)	6.4	8.6	10.5	12.0	15.2	18.8	21.9
Soybean (*Glycine max* (L.) Mew)	4.3	6.5	7.4	9.3	13.1	18.8	-
Sunflower (*Helianthus annuus* L.)	-	5.1	6.5	8.0	10.0	15.0	-
Wheat, white (*Triticum aestivum* L.)	6.7	8.6	9.9	11.8	15.0	19.7	26.3
Wheat, durum (*Triticum durum* Dest.)	6.6	8.5	10.0	11.5	14.1	19.3	26.6

Temperature

In general, the higher the temperature, the more rapidly a seed deteriorates at a given level. Seed moisture and storage temperature interact in influencing seed viability during storage. Low temperature is more effective than higher temperatures for storing seeds, but temperatures above freezing, especially between 5-0°C, have been considered adequate. Maintenance of low temperature is expensive, however.

Heat from external sources penetrates slowly into the seed bulk. Diurnal temperatures rarely affect seed below a few centimeters from the surface. The metabolic heat produced exclusively by dry seed is about 1×10^{-7} cal/sec/cm^3; and by damp seed/grain, approximately 1.3×10^{-5} cal/sec/cm^3. The amount of heat produced by fungi, insects, and other organisms invading the grain is considerably higher. In building better seed storage structures, important points to remember about temperature are:

1. Mites do not develop below 5°C (41°F), nor insects below 15°C (60°F).
2. Most storage fungi do not develop below 0°C (32°F).
3. The effect of temperature on an organism is correlated with the amount of moisture present, because a rise in temperature corresponds to the decrease in the relative amount of moisture in the atmosphere. Harrington's (1960) rule of thumb states that for each 1% increase in seed moisture, the life of the seed is halved. This applies when the seed moisture content is about 5-14%.

The rule further states that for each 5°C increase in temperature, the life of the seed is halved. This applies between 0-50°C. The two aspects of the rule apply independently. Thus, seeds having 10% moisture and stored at 20°C will survive about twice as long as those with 8% moisture stored at 30°C.

Physical Condition of the Seed

Most mechanical injuries to seed are not readily detected. Commonly used tests for mechanical injuries include observations of fractured seed coat or of seedling structures in growth tests. Symptoms of mechanical damage in standard growth tests are variable. They include detached seed structure, breaks within structures, abnormally shaped structures, scar tissue infections, restricted growth, unnatural shrinkage of cotyledons, and split or otherwise abnormally developed hypocotyls and primary roots. Injured roots often appear dwarfed and twisted and the tips often look blunt and dull.

Microflora and Insects

Storage fungi chiefly comprise several "group species" of the genera *Aspergillus* and *Penicillium*. These fungi do not invade grains to any extent before harvest. The major effects of storage fungi upon seeds are: decrease in germinability; discolored embryo, whole kernels, or seeds; production of mycotoxins; heating; development of mustiness and caking; and total decay.

Seed viability may be affected by the presence of insects in a number of ways:

1. If the insect becomes sufficiently abundant, it may render the storage environment harmful to the seed by simultaneously raising the temperature, moisture content, and CO_2 content of the atmosphere, and by depleting the oxygen.
2. The embryo may be damaged or killed by the feeding of adults or larvae or by oviposition.
3. Insects may introduce fungi that consume the seed or weaken or attack the seedling.
4. Insects may spin webs and construct cocoons that interfere sufficiently with the even flow of seed to necessitate cleaning, and also cause loss of seed.
5. Insect control measures may kill some seeds.

Good storage facilities are required to prevent and control storage insect infestations. Cooling and airtight storage can help in prevention.

Chemical methods of protection and control include fumigants, such as methyl bromide, hydrogen cyanide, phosphine, ethylene dichloride, carbon tetrachloride, carbon disulphide and naphthalene. Phosphine is very popular; doses are 3-6 g/m^3 (i.e., 1-2 tablets/m^3), with exposure for five days. A maximum of two or three fumigations should be given at 60 day intervals; after fumigation, the store should be thoroughly aerated. Contact insecticides can also be used, such as DDT (1 g DDT 10% dust/kg of seed), lindane, malathion, and others.

Gas During Storage

Seed moisture and various gases, individually or in combination, interact to affect the loss of viability during storage. An atmosphere of oxygen concentration greater than that of air hastens deterioration, while an atmosphere of carbon dioxide is reported to increase storage

life (seed moisture less than 6%). An atmosphere of nitrogen gas delays the onset of deterioration; however, once deterioration starts, it proceeds as rapidly as in air.

Currently, different gases are not utilized commercially for storage, but research interest on the subject is increasing.

Other Considerations

Since seed moisture and storage temperature are the two most important factors influencing seed viability during storage, it is essential to restrict their movement in the seed store. In constructing an improved storage structure, proper insulation must be provided against moisture and temperature migration.

Even with the best storage facilities, seed deteriorates if storage management is inadequate. Therefore, the storage behavior of seeds of different species and varieties within a species should be known to help plan seed storage. Seeds of species that store poorly, such as onion and soybean, should be sold in the season to avoid carry-over. In addition, proper ventilation should be ensured around seed bags. Bags should be stacked only on pallets with at least 10 cm open space for air movement and 20-30 cm open space between stacks and wall. Germination percentage of stored seeds should be checked regularly, and fertilizers, feeds, fuels, etc. should not be stored with seed. Stores should be kept clean, in good repair, and free from insects and pests by fumigation, seed treatment, space spray, poison baits, and other appropriate methods.

Seed Marketing

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Introduction

The process of seed marketing has two important purposes. One is to assess the demand for seed and related inputs; the other is to ensure that enough seed of the right quality is supplied to farmers at the right time, and at a reasonable price. Other essential farm inputs, such as fertilizers, fungicides, insecticides, herbicides, and farm implements must also be available.

In countries with a strong private seed sector, seed is usually distributed to farmers through effective private distribution networks. In other countries, seed is distributed through the general agricultural supply system, organized by the public sector. Such systems are often less effective and efficient.

Seed Demand

Assessing the potential seed demand is rather simple and is based on acreages, .seed rates, and renewal rates. Establishing the effective demand for high quality seed is more difficult, since it depends on many uncertain factors.

The effective demand increase depends mainly on the introduction rate and the replacement or renewal rate. Both rates depend in turn on many technical, sociological, economic, and institutional factors.

Introduction rate

The rate at which a new variety is introduced, or adopted by the farmer, depends upon a number of factors. The first is agronomic superiority, including the primary and secondary uses of the crop and the consumptive quality. The relation between costs and benefits also affects the rate. The increased yield must cover the extra price for the seed and other inputs, as well as produce a financial profit to induce the farmer to use the high quality seed. Prices must often be subsidized at the start. The type of crop also affects the adoption rate; farmers are often more willing to introduce a new crop if it can be grown as a second crop. Other factors include: the availability of inputs and markets to absorb the extra production, extension and promotion efforts, and the availability of credit.

Replacement rate

The replacement rate is the rate at which farmers replace the seed, instead of using their own harvested grain as seed. A farmer can usually save seed from the harvest of his commercial crop.

The genetic purity of a new variety will remain high for several generations, particularly for self-pollinated crops. Acceptable replacement rates are four-to-five years for self-pollinated crops; three years for cross-pollinated crops; and every year for hybrids.

Extension and promotion

One part of marketing is seed extension programs which advise farmers on the availability and use of quality seed of improved varieties. Farmers must also be convinced to use the seed, and trained in recommended production methods. In many countries, the government is responsible for extension, but private firms often have their own extension programs.

Many extension services are inadequate because they perform administrative and regulatory functions instead of transferring improved technology to farmers. They may also have insufficient links to research. Careers in the extension services may not be considered attractive, and extension officers often lack the necessary information about each crop under various growing conditions.

Credit

Agricultural credit has become an important tool which enables the farmer to use the quality seed and related inputs. In certain cases,

credit is advanced only if certified seed is used.

Seed market planning must cope with many uncertain factors. Also, because seed production takes several years, demand has to be assessed before the sales period.

Seed Supply

Seed must be produced where it is easy and efficient to do so, but preferably in an area not too far from potential consumers. The environmental conditions should be optimal to avoid genetic shift and risk of crop failure. The seed should be distributed to selling points in the growing areas before the farmer needs it.

Marketing channels

The seed moves from the producer to the consumer via the wholesaler and retail dealer, with each crop having its own particular pattern. The retail dealers play a crucial role; in fact, the success of a distribution network depends largely upon selecting sufficiently motivated retail dealers who are able to provide extension services.

There should be numerous retail outlets distributed over the growing areas near the farmers. The best dealers are those who already have contacts with the farmers and have established a basis of trust.

Transportation of seeds

In a comprehensive marketing system, transport is required for the distribution of seed to growers as well as collection, and also for distribution to wholesalers, retailers, and farmers. Depending on the infrastructure of the country and the volume to be transported, appropriate transport must be selected. Distribution is easier in a country with a good transport infrastructure.

Storage

Adequate storage is critical to the supply of good quality seed. Good storage is usually available at processing plants and wholesale distribution points but less so at retail distribution points. Good storage is particularly important in countries or regions with high temperatures and humidity.

Seed at low moisture content packed in vapor-proof bags will retain its germination capacity; very dry seed can withstand higher temperatures, but is more sensitive to mechanical damage.

Packing

Packing the seed requires special attention, not only to ensure that the quality of the seed does not change but also so that the seed appears attractive to the farmer. Seed should be packed at the right weight for easy handling by retail dealers and farmers, as well as in amounts appropriate for different farm sizes (in weights of 1, 5, or 10 kgs for small farmers). Bags, containers, and packages should be sealed and labelled, and opened or partly-empty bags should never be sold.

Price of seed

The seed price should cover the grain price, the additional costs of production, processing, and distribution, and a reasonable profit. Seed prices range from 150-300% of grain prices, but may be higher under unfavorable conditions or for hybrid varieties; prices, however, should not be too high for a farmer to pay. Subsidies might be needed initially to induce farmers to buy the more expensive certified seed and other farm inputs, but should not be necessary after five years.

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Techniques of Seed Production in Cereal Crops

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The major cereal crops grown in North Africa and West Asia are bread wheat (*Triticum aestivum* L.), durum wheat (*Triticum turgidum* L. var *durum*), and barley (*Hordeum vulgare* L.). All are essentially self-pollinated crops with an outcrossing rate varying from less than 1% to 4-5%. One important factor in the production of good, stable cereal crops is the availability of high quality seed of high-yielding cultivars.

Seed Production at the Initial Stage

Cultivar (or variety) development can be based on introductions or, more frequently, on hybridization, followed by some scheme of selection (pedigree, bulk, single seed descent, etc.).

In general, during the early generations (F_2 to F_4), the material is screened for easily observable differences in traits related to disease and insect reaction, earliness, and morphology (such as plant height, spike length, and grain color and size). Seed is increased on a plant (or head) basis or on a cross basis according to the methods of selection chosen. The promising material is advanced for further evaluation through yield testing, which may start at the F_4 or, more frequently, at the F_5 generation.

This type of testing is repeated for two to four generations (depending on the program). Simultaneously, material is scored for different attributes under stress conditions (diseases, insects, drought, heat, salinity, etc.). Tests for grain or straw quality are also needed to assess the material's economic value.

Before an advanced line is proposed for registration, it is tested on large replicated plots in farmers' fields or on government farms. Some breeders grow two or three of their most promising advanced lines in unreplicated demonstration strips or fields ranging in size from a fraction of a hectare up to a few hectares.

While there are no strict rules for seed increase during the yield testing process, during the first one-to-three generations of yield testing, the seed increased consists of the combined (bulk) harvest of all plots. The breeder examines his trials several times during the season and rogues out the off-types, taking care to avoid any serious damage to the plots. More fortunate breeders have enough land and labor to grow their material in unreplicated plots as well as in yield trials, and they use these additional plots for seed increase. These plots are examined several times during the season (once or twice before flowering and two or three times between flowering and harvest). The breeder eliminates the unwanted plants (off-types) and may either bulk-harvest the rest of the plot or make single head selection (20-50 heads/entry). When single heads are picked, the breeder carries out inter-row selection among the progeny in the following season, thus eliminating rows that are not typical of the entry. He then bulk-harvests the remaining rows. The ear-row procedure takes more time and effort but yields progeny that are generally more homogeneous. This process is usually started in the more advanced generations of testing (F_7 and later generations).

Seed Production at the Intermediate Stage

When a breeder has tested a line and wants to propose it for registration, he should have pure seed which will produce progeny of the desired type (in our case, progeny that are identical to the parental material). This seed usually originates from the harvest of ear-rows and is called breeder seed or pre-basic seed 1. In general, it amounts to a bulk of from a few hundred grams to a few kilograms. By this time, the line should have been submitted for registration. A committee usually comprised of researchers, representatives of the agricultural ministry, seed producers, and farmers' representatives either accepts or rejects the line, evaluating its overall performance relative to other lines or varieties based on yield, socio-economic factors, and other traits. Once registration is approved, the breeder, either at his research institution or in cooperation with qualified personnel from another public institution, proceeds to the multiplication of breeder seed or pre-basic seed 1 to get pre-basic seed 2. The latter can be produced in a single generation or in two or

more consecutive generations, depending on the program. Pre-basic seed is produced completely under the breeder's supervision. Further increase, yielding basic seed, is generally done by specialized seed production institutions, with the breeder still heavily involved in controlling the varietal purity.

Final Stage of Seed Production

While the breeder is involved in production of pre-basic and basic seed, seed produced from basic seed--called certified seed-- may be produced by specialized public or private organizations, with qualified personnel representing the ministry and/or the research institutions cooperatively inspecting the material in the field for varietal purity and freedom from seed-borne diseases and noxious weeds. Certified seed should also pass laboratory examination for seed moisture content, physical purity, germination, seed health, and, sometimes, 1000-seed weight. Although the same characteristics are checked for pre-basic and basic seed, standards for certified seed are more relaxed, and even less stringent for generations derived from certified seed, designated as certified seed 2, certified seed 3, and so on. This type of seed is generally produced in the early stages of seed production for a newly-released variety.

Other Considerations

At the breeding level, seed is produced under strict conditions ensuring genetic purity, physical quality, and good health. Genetic purity means the absence of seed of other varieties. Among the characters of physical quality are the absence of different crop species and weed seeds.

The breeder pays particular attention to: choosing the production land, keeping in mind the previous crop; ensuring isolation with borders and alleys to prevent mixtures; and cleaning of harvesting and threshing equipment. Good cultural practices generally ensure quality seed that is well-filled and highly viable. The health of seed undergoing multiplication is maintained through selection of a proper site, use of chemical treatments, and rogueing of diseased plants.

In general, it takes four generations from the time of registration to the distribution of certified seed to the farmer. (See Table 1 for nomenclature of seed multiplication steps.) An example would be: 1980-pre-basic 1; 1981-pre-basic 2; 1982-basic; 1983-certified; and 1984-commercial planting by the farmer.

Table 1. Comparative nomenclature used for seed multiplication steps.

OECD[1]	AOSCA[2]
pre-basic	breeder
basic	foundation
certified 1st generation	registration
certified 2nd generation	certified

[1]Organization for Economic Cooperation and Development.

[2]Association of Official Seed Certifying Agencies.

Certain programs have only one pre-basic seed, while others have three or more. Other programs have certified seed 1, certified seed 2, and so on. Some breeders proceed to bulk-increase of material that has gone through yield testing, and they may start the ear-row process simultaneously by growing a limited number of ear-rows the first year, but they do not necessarily wait for these ear-rows to begin multiplying the variety. Table 2 compares two procedures: bulk and ear-row increase for obtaining certified seed.

Every year, the breeder alone or in cooperation with the seed production agency must make head selections, so that there are all kinds of generations each year.

In all phases of cereal seed production, care must be taken to avoid waste and increase economic efficiency, because production of quality seed is an expensive enterprise. Seed production problems that may arise due to unfavorable circumstances (e.g., severe drought, frost, heat, and hail) should be alleviated through careful planning and crop management.

Table 2. Comparison of bulk and ear-row increases.*

		Starting	
		Bulk	Ear-row
1980	Breeder	20 kg	2000 rows
1981	Pre-basic	400 kg	75 kg
1982	Basic	8000 kg	1500 kg
1983	Certified 1	200 tonnes	37.5 tonnes
1984	Certified 2	5000 tonnes	937.5 tonnes

*A higher multiplication factor is assumed for later generations (25) than for earlier generations (20) because of differences in seeding rate and planting pattern.

Cultural Practices for Cereal Seed Production

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In a breeding program, a new selection which has proven superior after three years of multilocation testing for disease, yield, and adaptability for a region or regions should be increased for possible release. By this time, the genotype will be largely stable genetically. Head selections should be made during the third year of trials from seed increase blocks of that year. At least 1000 heads should be selected for plant row increase to produce breeder seed. With three years of data available, head row increase can begin. When this seed has been produced, at least four years of yield data, five or six years of disease information, and two or more years of quality evaluation data will be available. The decision should then be made on proceeding with variety release and final seed increase. If a variety is subsequently designated for release, final seed increase should proceed quickly to make the variety available to farmers as soon as possible. An improved variety can begin to be produced only after an aggressive evaluation program of prospective selections and a vigorous seed increase program.

High quality pure seed is the result of proper techniques in all phases of production. The agronomy of production will determine the purity and quality of the seed delivered to the processing plant, which can only upgrade the seed it receives by removing foreign material and sizing the seed; removal of admixtures of varieties and of all weed seeds is difficult.

Land Selection for Seed Multiplication

Seed should be produced on carefully-selected land that is free from weeds and volunteer cereals of the same class. The earlier the generation, the more care that should be exercised in land selection. For breeder seed, only a limited area is needed, but only high production land in a good rainfall area is suitable.

If irrigation is available, the first generation seed will be protected against drought, making maximum increase possible. Areas with climatic hazards such as frost, hail, drought, or flooding should be avoided for initial increases.

Knowing the previous cropping history is important in selecting land. Wheat should be planted after one year of clean fallow or after a dry legume, vegetable, or industrial crop. Irrigated land following alfalfa that has been in production three or more years is ideal. For seed production, wheat should not follow a forage crop of vetch and oats or another cereal crop.

As the quantity of land required for seed production increases with each generation, it becomes more difficult to maintain high standards of land selection. If land meets the standards of rotation and freedom from volunteer crops, the next criterion must be the weed situation. Fields with noxious perennial weeds should be avoided, especially if seed produced by these weeds is difficult to remove by processing. Heavy infestations of wild oats and grassy weeds cause difficulty in rogueing short-statured varieties and reduce yields. Fields with a history of wild oats must not be used for the increase of basic and registered cereal seed. Fields for later generations should be selected to avoid weed problems as much as possible, and herbicides must be available to control wild oats, other grassy weeds, and broadleaf weeds in cereal production.

Experiment stations should be used for seed production only if the land and climatic conditions meet seed production standards. If experiment station land is used to produce seed, the land must be rotated and managed for seed production, which requires proper planning. The multiplication of breeder and basic seed should be controlled and supervised by the breeding and seed production staff, whether on or off the experiment station. Cereals are too often multiplied in early generations on land that does not meet the standards for maximum increase of breeder and basic seed.

Special Management for Seed Multiplication

The practices of seedbed preparation, fertilizing, and weed control required for seed production are the same as those for maximum cereal

production. These practices result in a prepared seedbed free of weeds and germinating seeds. Seeding, fertilizing, herbicide applications, rogueing, and harvest must be timely and performed with proper equipment.

Seeding rate and row spacing are important management practices in seed multiplication. The rapid increase of early generations can reduce the time necessary to produce the seed volume required for commercial production. In the production of breeder, basic, and certified seed, maximum multiplication from the limited seed supply is more important than maximum yield per hectare. The seed should be planted at a rate and manner to give maximum multiplication per unit of seed available. Decreasing seeding rate is the most practical way to increase early generation multiplication in both dryland and irrigated production.

A row spacing and seeding rate experiment in 1976 at El Khroub, Algeria tested the effect of reducing rate and increasing row spacing on seed multiplication in early generations. The experiment used seeding rates of 40, 80, and 120 kg/ha at 17.5 cm row spacing; and 33, 50, and 100 kg/ha at row spacings of 51.5, 35, and 17.5 cm, respectively. In one experiment, row spacing was kept the same but seed density within the row was varied. In the other experiment, row spacing varied but the seed density within the row remained the same. Rainfall was adequate for maximum production. Fertilizer nitrogen was applied at 100 kg/ha in two equal applications at seeding and tillering. Phosphate was applied at seeding with the seed at a rate of 45 kg/ha. Results are given in Table 1.

Table 1. Effect of seeding rate and row spacing on Anza wheat, El Khroub Station, Algeria, 1975-76.*

	Seeding rate (kg/ha)	Row spacing (cm)	Plants/ m^2	Heads/ m^2	Tillers/ plant	Yield (kg/ha)	Yield (kg/100 kg seeded)
	120	17.5	258	624	2.4	5543	4619
	80	17.5	172	562	3.3	5393	6737
	40	17.5	86	453	5.3	4683	11708
CV%			2.6	6		35	
05							
LSD			8.26	30.8		430	
	100	17.5	236	590	2.5	5152	5152
	50	35.0	115	391	3.4	4267	8534
	33	52.5	80	325	4.1	3562	10594
CV%			7.8	9.3		85	
05							
LSD			30.8	72		641	

*Nelson 1976.

Yield was decreased about 10% (5152 to 4683 kg/ha) when the seeding rate was decreased from 100 to 40 kg/ha at the same row spacing of 17.5 cm. Since the seeding date of 5 January 1976 was about one month late, tillering was reduced and yield decreased more than would be expected with an earlier seeding date. Increased row spacing with the same density within the row affected yield more, yet the seed increase/kg of seed seeded was greater whenever seeding rate was decreased, regardless of row spacing. Decreasing seeding rate appears to be the best way to increase multiplication of a given quantity of seed.

In Table 2, the effect of five seed densities on five varieties is given for a trial at Tel Hadya in 1980/81. Actual seeding rate in kg/ha varied for each variety at each density, but the same number of viable seeds were planted at each density. All other production factors remained the same for all varieties. The seeding rates were calculated from the actual counts per m^2 by converting from seed weight/1000 kernels, assuming 80% germination.

The data in Table 2 show that seeding rates below 20 kg/ha are even more effective for maximum seed increase than do the data in Table 1. More research on row spacing combined with low seed rates should be conducted to find the optimum combination for production of basic seed.

Cereals' high yielding ability at low seeding rates, especially that of wheat with its relatively small seed size, allows very rapid seed increase. This was demonstrated when the variety Gaines was released in the USA in 1960. Over two years, 1.36 tons of seed was increased to 15,000 tons with two crops--an increase ratio of 11,000:1 in two cycles.

The following recommendations facilitate rapid increase:

1. Increase the number of head rows and spacing between rows to double the breeder seed available.
2. Increase the breeder seed at the seeding rate of 20 kg/ha under the highest production conditions possible.
3. Increase the basic seed at 40 kg/ha under good management at the highest production conditions possible.
4. Provide empty rows to facilitate rogueing, application of herbicides, and top dressing of fertilizer. If the empty row pattern matches the tractor tread and is wide enough for the tractor tires, tractor operations will cause minimum damage to the cereal crop.

Table 3 compares increasing seed at 100 kg/ha to the lower rates suggested in Tables 1 and 2. By increasing breeder seed 100% and then decreasing seeding rates, about 16 times as much seed could be produced (at conservative yield estimates) for production at the lower seeding rates. Exact yields could vary, but the ratio of increase would approximate that given in Table 3, based on the data in Tables 1 and 2 and also on actual records of seed increase of new varieties.

Table 2. Effect of plant density on yield of five varieties at five different seeding rates; Tel Hadya, 1980/81.*

Variety	Seeding rate (kg/ha)	Yield (kg/ha)	Ratio of yield/kg of seed
	16	3034	190
	26	4030	155
Veery"s"	65	6863	75
	126	4154	33
	191	4032	21
	17	3093	182
	29	3957	136
Alondra"s"	73	3664	50
	144	3979	28
	214	3259	15
	18	4067	226
	31	3957	128
Condor"s"	66	4579	69
	177	4175	36
	205	4211	21
	19	3934	207
	29	4054	140
Buck buck"s"	64	4076	64
	119	3919	33
	185	3299	18
	13	3238	249
	24	4731	197
Jup "cross"	46	4105	89
	84	4482	53
	135	3939	28
	17	3437	204
	28	4146	148
Average of	63	4258	68
5 varieties	118	4142	35
	186	3728	20

* W. Anderson, ICARDA, unpublished data.

Table 3. Estimated seed increase comparing normal seeding rates to reduced rates with similar production potential.

Generation	Seed quantity (quintal)	Seeding rate	Area of seed (ha)	% area increase	Estimated yield (quintal/ha)	Total production qtls
Breeder seed						1
Basic seed	1	100	1	0	40	40
Registered seed	40	100	40	0	35	1400
Breeder seed						2
Basic seed	2	20	10	1000	30	300
Registered seed	300	40	750	1875	30	22500

The purity of seed produced decreases with each generation of seed increase through mechanical and volunteer mixtures. If the number of generations needed to multiply the seed for commercial production is decreased, seed purity will be greater when the seed goes into commercial production.

Seed multiplication of an improved variety is perhaps the most important part of a variety development program. It is successful only when it uses land suitable for seed production. The loss of an early generation seed source due to improper land selection will delay the increase by one or two years. Increase sites for early generation seed must therefore be selected to control all possible hazards. All means should be employed to get the maximum seed increase in the first two or three generations of increase. Poor land selection and preparation, seeding, fertilizing, and spraying reduce the rate of seed multiplication, delay the benefits to the country of the new improved variety, and can result in complete loss of a valuable seed source.

A multiplication program that rapidly increases new improved varieties, and maintains reserve stocks of recommended varieties, will help stabilize and improve production. It is especially important to have reserve stocks of early varieties that can be used when weather conditions necessitate late seeding, as well as a reserve stock of good seed from older recommended varieties.

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Principles and Techniques for Seed Production in Chickpea

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Chickpea (*Cicer arietinum* L.) is a self-pollinated annual species. The rate of natural cross-pollination has been reported to be between 0 and 2% (Gowda 1981). Chickpea is widely grown in the Indian sub-continent, the Mediterranean region, East Africa, and Mexico, and efforts are underway to popularize it in North America, Australia, and parts of east Europe and South America.

In recent years, the research effort on breeding for the development of improved cultivars has been increased substantially. Many countries that have not yet produced improved cultivars are now at a stage to release them. The impact of these cultivars on production will greatly depend on the seed industry. Unfortunately, the seed industry for chickpea has been developed only in a few countries, such as India, Pakistan, Iran, Egypt, and Mexico. Therefore, this paper aims to describe norms that may be helpful in setting up seed industries in various countries of the region.

Development and Release of Cultivars

It is not intended to discuss the development of improved cultivars in detail, but it is appropriate to mention how chickpea cultivars are usually developed; that is, through introduction of finished or segregating materials followed by pure line selection, and through hybridization followed by pedigree, bulk, or backcross methods of selection.

Once a number of pure lines are developed, they are evaluated for a number of years in areas of adaptation. When a new line is found superior to standard cultivars in grain yield, quality, disease resistance, or other important traits, it is released for cultivation. Thereafter, the seed production agency can play an important role in popularizing the cultivar and increasing production.

As mentioned earlier, the seed production industry for chickpea in West Asia and North Africa is underdeveloped. ICARDA's introduction of high-yielding, ascochyta blight-resistant, cold-tolerant, and widely adapted cultivars for winter sowing, such as ILC 482 and ILC 3279, provides an excellent opportunity to develop the seed industry in these regions. Since these cultivars can yield at least 50% more than the best local spring-sown cultivar, they can act as a catalyst for the development of a chickpea seed industry.

Identification of Cultivars

Two types of chickpea, both generally erect and bushy, are grown in the world: desi (with small, angular, colored seed), and kabuli (with large, ram-shaped, beige-colored seed). These two types are shown in Figs. 1 and 2. It is relatively easy to differentiate between desi and kabuli types, but it is often difficult within a given type to distinguish one cultivar from another. Nevertheless, there are certain criteria which can be helpful in identifying the cultivars. It is therefore suggested that detailed records of various characters are kept when a cultivar is released. Some important characters are mentioned below.

1. Morpho-agronomic characters

- Plant type: erect, semi-erect, semi-spreading, and spreading.
- Stem: color, thickness.
- Leaf: color, size (large, medium, small).
- Branches: number of primary, secondary, and tertiary branches/plant.
- Plant height: in centimeters, and tall, mid-tall, and conventional type.
- Flower: days to 50% flowering, color, and size.
- Maturity: number of days to maturity.
- Pod: number/plant, number of seeds/pod, and size.
- Seed: 100-seed weight, roughness, shape, and color.
- Any marker gene: for example, simple leaf.

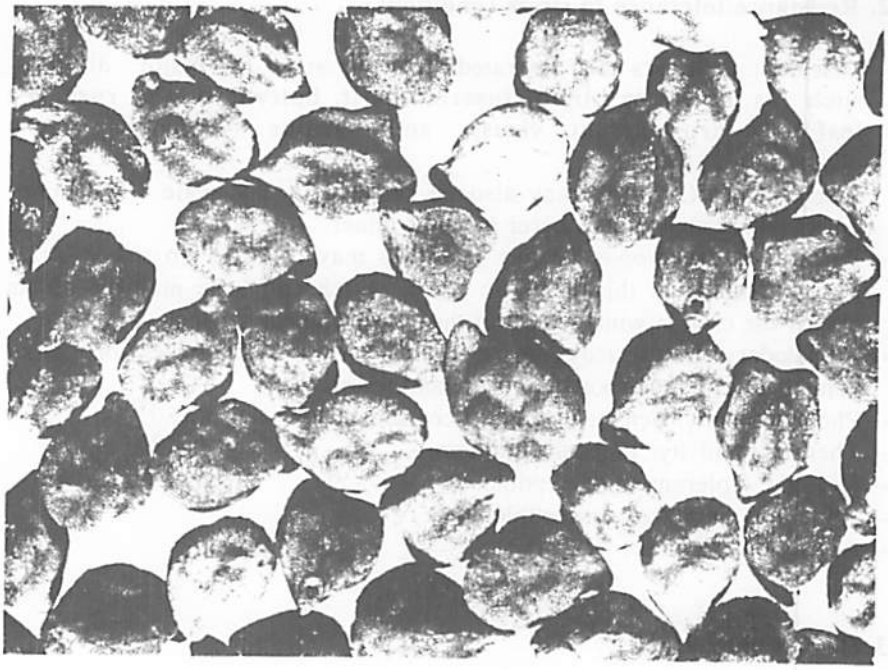

Fig. 1. Desi-type chickpea

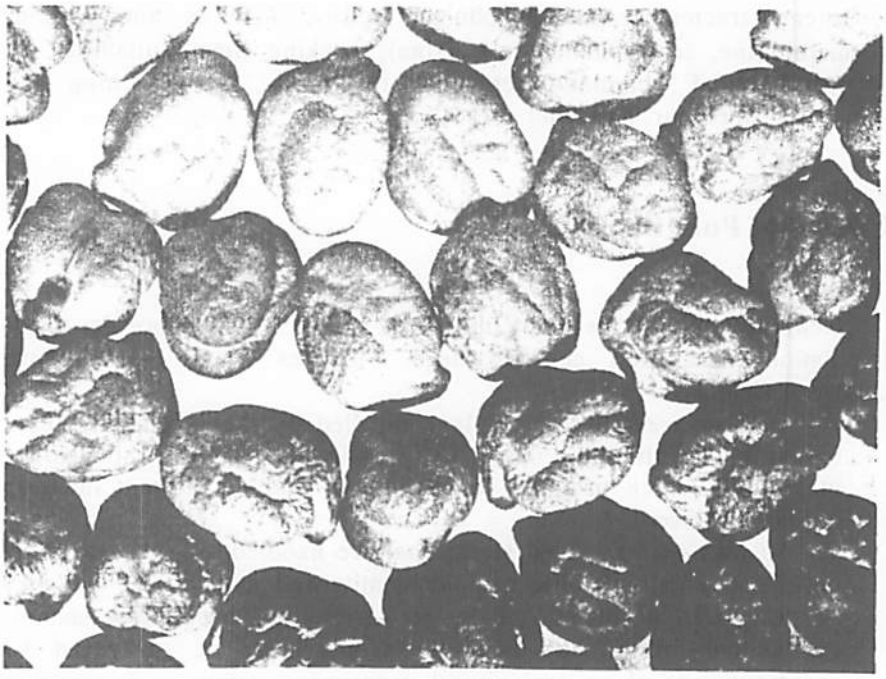

Fig. 2. Kabuli-type chickpea.

2. Resistance/tolerance to stress conditions

- Diseases: Cultivars may be rated on a 1-9 scale for major diseases, such as ascochyta blight, fusarium wilt, botrytis blight, rust, pea leaf roll virus (stunt virus), and various types of root-rot diseases.
- Insect pests: Cultivars may also be rated on a 1-9 scale for major insect pests, such as pod borer and leaf miner.
- Parasitic weed/*Orobanche* sp.: Cultivars may be rated on a 1-9 scale for resistance to this parasitic weed, which can be a major problem only if the crop is winter-sown in the Mediterranean region.
- Nematodes: Lines may be evaluated on a 1-9 scale for major nematodes, such as root knot, cyst, and lesion.
- Photosensitivity: Sensitive and reduced sensitivity.
- Thermosensitivity: For cold and heat.
- Drought: Tolerant or susceptible.
- Salinity: Tolerant or susceptible.
- Any other character.

3. Quality characters

- Protein content (%).
- Other characters depending upon the facility, such as amino acids (methionine, tryptophane, and lysine); cooking time; suitability for preparation of "hommos-bi-tehineh", for candy, for parching and roasting, for flour, and other uses.

Classes of Pure Seed

Generally, three classes of pure seed are recognized: breeder seed, foundation seed, and certified seed. Hayes *et al.* (1955) have described them as:

1. *Breeder seed:* Seed directly controlled by the originating plant breeding institution (or, in certain cases, the sponsoring institution) which provides for the initial and subsequent increase of foundation seed.
2. *Foundation seed:* Seed stocks that are handled so as to most nearly maintain specific genetic identity and purity, and that may be designated or distributed by an agricultural experiment station. Production must be carefully supervised or approved by representatives of an agricultural experiment station. Foundation seed shall be a source of all other certified seed classes.

3. *Certified seed:* The progeny of foundation or certified seed that is handled so as to maintain satisfactory genetic identity and purity, and that has been approved or certified by a certifying agency.

Purification of Breeder Seed

Often the seed of a cultivar becomes somewhat impure due to natural outcrossing, mechanical mixture, mutation, or some other reason. This necessitates purification of the cultivars from time to time.

In the common purification method, approximately 2,500 seeds are sown in a bulk plot, providing enough space between and within rows (45 x 20 cm) for observations on individual plants. Five-hundred phenotypically similar plants are chosen with the characteristics described for the cultivar at the time of release. The plant rows are sown the following year and detailed observations are recorded on each. Progeny that differ from the original description are rejected. Seed from progeny is then tested the following year for any special characteristics such as disease resistance, or for any quality characters. The seeds of the progenies that are similar in agro-morphological and quality characters, resistance to various stresses, and yield are then bulked and treated as pure seed of the cultivars. The entire process is periodically repeated.

Seed Certification

The following conditions and procedures are suggested for producing certified chickpea seed.

1. *Selection of land:* Due to the problem of volunteers from the previous season's crop, it is essential in seed certification to avoid a field that was under chickpea the preceding season.
2. *Disease-free soil:* Some diseases such as ascochyta blight and fusarium wilt are seed-borne, so seed produced from infested plots should be rejected. Chickpea seed should also be produced in non-endemic areas.
3. *Field inspection:* A minimum of two inspections are generally done between flowering and harvest. During field inspection, observations on a few key points are recorded, including off-type, objectionable weed plants, and seed-borne diseases. A minimum of 500 plants should be taken per count for recording observations. (The number of counts to be taken during field inspection is discussed elsewhere in this book.)

4. *Isolation distance:* Since chickpea is a self-pollinated crop and natural cross-pollination is either negligible or non-existent, isolation distance between two cultivars helps in maintenance of purity by avoiding mechanical or manual mixing at harvest. A minimum isolation distance of 20 m should be maintained between different cultivars for increase of foundation seed, and of 10 m for certified seed.

5. *Off-types:* The off-types should be eliminated if possible; if not, the maximum permitted percentage is 0.10 for foundation seed and 0.20 for certified seed.

6. *Seed standards:* The seed standards for foundation and certified classes are suggested in Table 1. For breeder seed, 100% pure seed is required and any inert matter is unacceptable.

7. *Seed dressing:* Since ascochyta blight and fusarium wilt diseases are seed-transmitted, it is advisable to treat the seed with suitable fungicides, if the seed has been harvested from plots infested with these diseases. Calixin M for ascochyta blight (Reddy 1980) and Benlate T (benomyl and thiram) (Haware *et al.* 1978) for fusarium wilt have been found effective. Bruchids (*Callosobruchus chinensis*) reduce germination, and seed dressing with Actellic insecticide is known to eliminate this insect.

Table 1. Suggested seed standards for chickpeas*.

Factor	Class standards (%)	
	Foundation	Certified
Pure seed (min.)	98.0	98.0
Inert matter (max.)	2.0	2.0
Other crop seeds (max.)	0	0.05
Weed seeds (max.)	0	0
Germination including hard seeds (min.)	85.0	85.0
Moisture (max.)	9.0	9.0

*Personal communication with P.K. Agrawal, Indian Agricultural Research Institute.

Production of Ascochyta Blight-Free Seed

Blight caused by *Ascochyta rabiei* (Pass.) Lab. is the most important chickpea disease in the Mediterranean region, Pakistan, and northwestern India. Since this disease is seed-borne, it is important to produce ascochyta-free seed for distribution in the endemic area and also to prevent introducing this disease into uninfected areas where environmental conditions may favor spread and development of blight. Kaiser (1984) has cited the following conditions and precautions as helpful for the production of chickpea seed. These practices can prevent the introduction of ascochyta blight into disease-free areas or significantly reduce or eradicate the disease in infested areas.

Arid environment

Ascochyta blight of chickpea depends on cool, wet weather for its greatest spread and development. Surface-contaminated or internally-infected seed is the most important means of spreading and perpetuating the disease. Dry, warm weather impedes disease development and spread. It is preferable to locate seed production fields in arid areas where little or no rain falls during flowering, fruiting, or harvest.

Crop rotation

It is highly desirable to grow chickpeas in rotation with other crops such as cereals to prevent the buildup of *A. rabiei* on any infested trash left in the field after harvest. Since only chickpeas are susceptible to ascochyta blight in nature, ascochyta propagules on chickpea refuse begin to lose viability as the debris begins to decompose. Certain practices such as ploughing will speed up refuse decomposition.

Field sanitation

It has been reported that *A. rabiei* is able to multiply on chickpea refuse left in the field after harvest, thereby providing a potential source of fungal inoculum which may initiate new centers of infection from rain-splashed conidia. Therefore, any chickpea refuse in the field after harvest should be burned or buried. Deep ploughing will hasten the decomposition of infested straw and eliminate it as a source of fungal inoculum.

Chemical seed treatment

Chickpea seeds introduced into an ascochyta blight-free area should be treated with an effective fungicide as a precaution against inadvertently introducing the pathogen on infected seed. This is particularly important with seed of uncertain origin. Treatment of chickpea seed with some of the newer systemic fungicides offers great promise in controlling surface and deep-seated infection by *A. rabiei*. Reddy (1980) reported the eradication of *A. rabiei* in naturally infected chickpea seeds with the systemic fungicide tridemorph (Calixin M) used alone or in combination with benomyl.

Field inspection

Ascochyta blight can be present in chickpea plantings at low levels, making detection difficult. It is therefore essential that trained, qualified personnel inspect seed fields carefully at periodic intervals up to the time of harvest.

Time of sowing

In spite of the very high yield potential of winter-sown chickpeas in West Asia and North Africa, it is recommended to sow the chickpea crop for seed increase only during spring. This practice may allow the production of ascochyta-free seed.

Production of Wilt-Free Seed

Like ascochyta blight, wilt caused by *Fusarium oxysporum* is a seed-borne disease. Seed dressing with Benlate-T has been found effective in eradicating the wilt pathogen from seed (Haware *et al.* 1978). Wilt commonly occurs if the crop is grown under high temperatures which often exceed 30°C. Some of the measures for producing wilt-free seed are briefly described here. First, chickpea seed should not be multiplied in a field or area known to be infested with the wilt pathogen. Crop rotation has been found beneficial in checking any further buildup of the pathogen, and plants showing symptoms of wilt in a seed multiplication plot should be destroyed. Finally, seed should be dressed routinely with Benlate-T in any area where wilt is known to be a problem.

Setting up a Seed Laboratory

A seed laboratory is required for seed certification. The laboratory is generally used for determining seed purity, germination, moisture, weed seed content, seed health, and other characteristics. Such laboratories already exist in most countries and can be used for chickpea seed certification work as well.

Seed Production

There are no fixed standards for the number of times that certified seeds acquired by the farmer can be used, but it is generally accepted that seeds can be used for four years and should be replaced every fifth year. The land requirements for different classes can be determined as follows:

Assumptions:
1. Acreage: 100 ha
2. Certified seed required for each year = 100/5 = 20 ha
3. Seed size: 30 g/100 seeds
4. Seeds required for 1 ha = 100 kg
5. Multiplication ratio = 20 times

Area required: Certified seed: 20/20 = 1.0 ha
Foundation seed: 1/20 = 0.05 ha
Breeder seed: 0.05/20 = 0.0025 ha

As seed size is highly variable, the area required for seed increase will vary. The area required for increase of various classes at three seed sizes--15, 30, and 45 g/100 seeds--for 1000 ha has been estimated (Table 2). The area required for other seed sizes and areas can be calculated from this table.

Concluding Remarks

World chickpea production has remained static for the past three decades, and the lack of a seed industry is one of the causes. There is a strong possibility to build up a seed industry using cultivars developed for winter sowing as a base in the Mediterranean region. Another favorable factor is the high selling price of chickpea, which has made its cultivation more remunerative. National program scientists should exploit this opportunity to build up a chickpea seed industry.

Table 2. Land required to produce certified, foundation, and breeder seed for 1000 ha chickpeas.

Seed size	Area (ha)		
(g/100 seed)	Certified	Foundation	Breeder
15	5	0.25	0.012
30	10	0.50	0.025
45	15	0.75	0.037

Acknowledgements

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Techniques of Seed Production in Lentil

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Introduction

Lentil (*Lens culinaris* Med.) is an annual self-pollinated legume grown throughout the Mediterranean and West Asian region. The crop is still under-exploited, and breeding efforts in the region have resulted in the release of only a handful of cultivars. Most of the lentil area is sown with landraces, each of which contains considerable variability maintained in a mixture of pure lines, since the rate of outcrossing does not exceed 1% (Wilson and Law 1972; Skibinski *et al.* 1984). The released varieties in the region include Giza 9 (ILL 784) from Egypt and the Kislik series from Ankara: Pull 11, Yesil 21, Yesil 31, and Kirizi 51. Lentil improvement is now receiving more attention in national breeding programs and at ICARDA, and improved varieties will consequently become available. However, there is presently a lack of information on seed production and certification of the crop. An authoritative reference book on other aspects of the crop is *Lentils* (Webb and Hawtin 1981). Seed for certification is inspected in the field for checking the field standard and in the laboratory for seed standard.

Laboratory Tests

In the laboratory, seeds are tested for moisture, purity, germination, and seed health and compared against pre-set standards for seed certification.

Sample composition: Seed may be defined as such if it is more than half the original size with testa attached. Decorticated and/or split seed are common impurities of roughly threshed lentils. Seeds damaged by weevils (*Bruchus* spp. and *Callosobruchus* spp.) (Hariri 1981) are also considered impurities.

Other impurities include inert matter and seeds of weeds and other crops. Standards for these factors are suggested in Table 1 (P.K. Agrawal, Indian Agricultural Research Institute, personal communication). Amongst these impurities, some legume weeds pose a particular problem because of their similarity to lentils in seed characters. For example, a variety "Chilean" in the state of Washington, USA became so infested with *Vicia sativa* seed that it was withdrawn; thereafter, the identical but cleaned seed of Chilean '78 was released.

Table 1. Suggested seed standards for lentils.*

Factor	Class standards (%)	
	Foundation	Certified
Pure seed (min.)	98.0	98.0
Inert matter (max.)	2.0	2.0
Other crop seeds (max.)	0.1	0.2
Weed seeds (max.)	0.1	0.2
Germination including hard seeds (min.)	75.0	75.0
Moisture (max.)	9.0	9.0

*P.K. Agrawal, Indian Agricultural Research Institute, personal communication.

Sample validity: Validity is measured by comparison with a description or with pure seed. The following characters may be used to test validity:

- Seed weight (g) of 1000 random seeds.
- Background color of seed testa (green, pink, brown, grey, or black). All color characters should be examined in daylight on freshly harvested seed.

- Pattern on testa (as shown in Fig. 1: absent, dotted, spotted, marbled; or complex/combination of patterns).
- Color of pattern on testa (olive green, grey, brown, or black).
- Cotyledon color (red, yellow or green (turns yellow with age)).
- Destructive sampling by removal of testa to see seed cotyledon color.

A minimum of 98% of the seed must conform to type for both foundation and certified seed.

Seed viability: Germination tests on lentil should be done at 20°C between paper after pre-chilling to 2°C, with the first count of germination after five days and the final count after 10 days. A minimum of four batches of 100 seeds are required for germination tests. For seed health, either the blotter method or the agar plate method may be used (Anon. 1976). Moisture tests may also be run (Anon. 1976).

Seed dormancy due to hard seed coat in lentils is reported to be lost after 90 days of storage under natural conditions (Agrawal 1982). Dormancy has been successfully overcome by seed stratification at 5° C for 48 hours (Muehlbauer and Slinkard 1981).

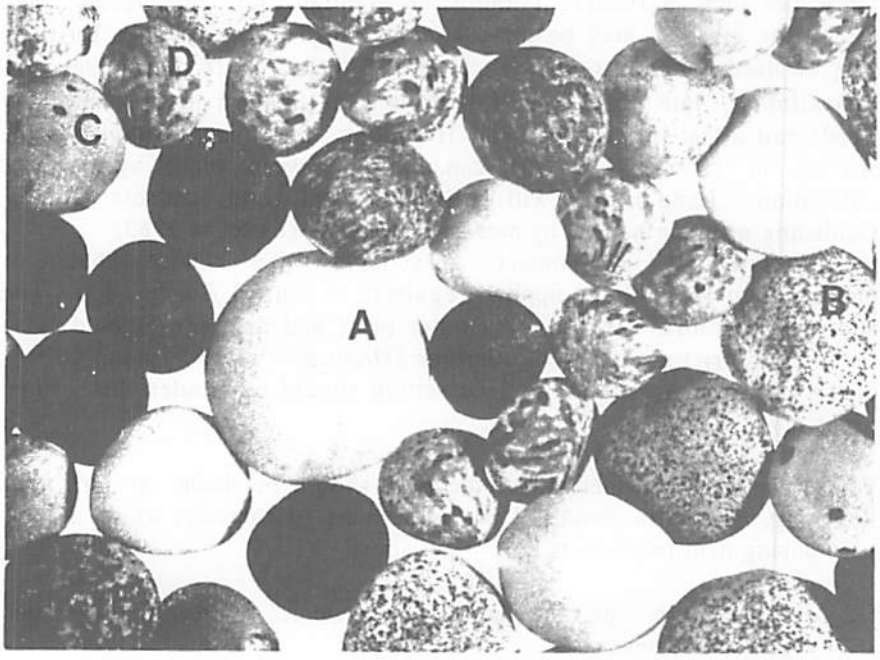

Fig. 1. Pattern on lentil seed testa.

A: absence of pattern; B: dotted; C: spotted; D: marbled; E: complex.

Seed Production

Site selection: The crop is not eligible for certification if it is planted on land on which the same species was grown within the previous two seasons, unless the previous crop was grown from certified seed of the same variety. It is also important to avoid sites with a history of *Orobanche* infestation. In case of crop failure, two parcels of land in separate fields are preferable to one area. For both foundation and certified seed production, an isolation distance of at least 5 m should be left between the plot and fields of other varieties (Agrawal 1984).

Management for seed production: The husbandry for seed production is the same as for crop production with the exception of seed rate. Drilling should be at one half the crop density. In the Middle East, a seed rate of 200 plants/m^2 is optimum for crop production (Saxena 1981), whereas a rate of 100 plants/m^2 is required for seed production.

The following comments are equally applicable to seed or crop production. Fertilization with P_2O_5 on low phosphate soils may be recommended prior to planting. Inoculation of the seed with *Rhizobium* may be necessary in some cases. Weed control with pre-emergence herbicides such as Bladex, Tribunil, or Maluran for broadleaves, and Kerb for grasses, may be done after drilling. Alternatively, Fusilade may be used as a post-emergence grass killer. If herbicides are unavailable, late planting following a cultivation to kill the early weeds can assist in weed control. If enough land is available, wide spacing of rows (37.5 cm) can also allow weed control by inter-row cultivation. Land rolling will level the soil and depress stones, facilitating machine harvest by mower or combine (Papazian 1983).

At flowering, a contact insecticide like endosulphan or methidathion should be applied regularly to control *Bruchus* spp. The appropriate control measures for other pests and diseases should also be taken. Strict control of broomrape (*Orobanche* spp.) by hand pulling of the inflorescences prior to seed setting should be undertaken when necessary.

Field inspection: Inspection of the field should be made at or after flowering, with a minimum of two inspections. Characters which may be used during field inspections are:

- Anthocyanin pigmentation of stem, leaf, and pod (presence/absence)
- Leaf pubescence (presence/absence)
- Color of flower standard (white, white with blue veins, blue, violet, pink, or rose)

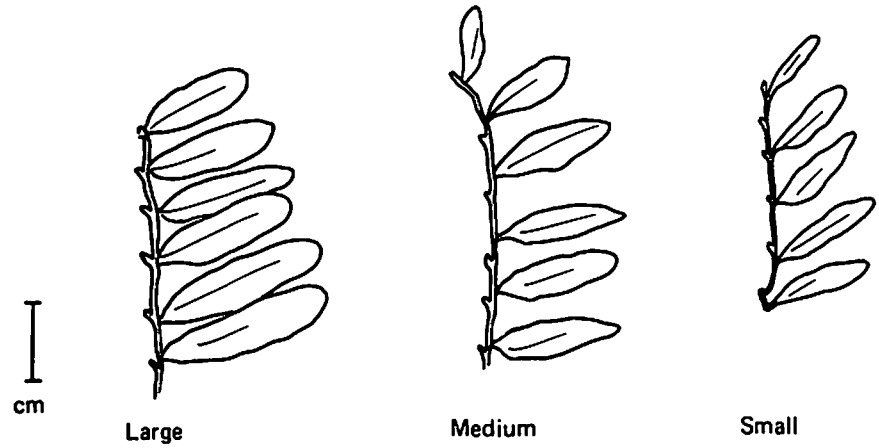

Fig. 2. Leaflet width of fully expanded leaves from the lower flowering nodes.

- Plant height (cm)
- Time to first flower (days)
- Leaflet size as observed at flowering (Fig. 2).

The maximum off-type content allowed in a sample is 0.10% for foundation seed and 0.20% for certified seed.

If a sample meets the requirements given in Table 1 in both laboratory and field tests, it may be stated that the name given by the sender does not seem incorrect, and the seed may be certified.

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Problems of Seed Production in Forage Crops

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Introduction

A breeding program has a practical impact on agriculture only when farmers decide to replace an old variety with a new one. This is possible only if the genetic integrity of a new variety is maintained, and if the seed is produced and distributed in commercial quantities. Maintaining the variety's genetic integrity is important because it is the base of the certification procedure, which is itself the only guarantee of the variety's genetic qualities.

The complex process by which the small amount of breeder seed is multiplied into tons of certified seed requires solving both genetic and agronomic problems. But in each of the groups of species classified by mating system--that is, species that are vegetatively-propagated, cross-pollinated, or self-pollinated--there are specific problems of variety maintenance and seed production. A major reason is that the term "variety" carries a different meaning in each of the groups.

Vegetatively-propagated species: In these, a variety is a "clone"; i.e., the progeny obtained by vegetative propagation of a single plant. Such a population will display only environmental variability, except for new mutations which in turn can be used rapidly and easily to create new varieties. The maintenance of varieties of vegetatively-propagated species does not present genetic problems, but may be complicated by the possibility of transmitting viruses, bacteria, etc. to new generations.

Self-pollinated species: In most of these, a variety is, genetically speaking, a "pure line"--the progeny obtained by selfing a homozygous plant. Theoretically, such a variety is expected, like a clone, to show only environmental variability. But the genotypes of a pure line are all homozygous, while those of a clone may be either homozygous or heterozygous, depending on the mother plant's genotype.

Actually, however, the varieties of a self-pollinated species do not strictly follow the expectations of Johannsen's experiments; instead, they show variability that is not only environmental. A series of experiments has shown that either because of a heterozygote's advantage (Allard *et al.* 1968), or because of micro-mutations (Gaul 1968), the amount of heterozygosity in varieties of self-pollinated species is higher than expected. This has led some authors to claim that the "pure line" is an abstract concept (Gaul 1968), and it is now widely accepted that to maintain the genetic integrity of these varieties, careful maintenance selection is needed.

Cross-pollinated species: Populations of these species have a genetic structure that differs from self-pollinated species. These populations have been defined as "reproductive communities which share a common genetic pool" (Dobzansky 1951). A peculiar characteristic of cross-pollinated species is the amount of genetic variability within populations, which is much higher than the variability within populations of self-pollinated species. This variability has enormous significance for both breeding and seed production. Genetically speaking, a variety of a cross-pollinated species can be either a clone, a hybrid, or a population more or less in genetic equilibrium (such as synthetic varieties, or varieties produced by mass selection or recurrent selection).

With the exceptions of hybrid varieties and clones, the varieties of cross-pollinated species are not genetically homogeneous; they are actually composed of a multitude of different, highly heterozygous genotypes. It is the mating system which maintains a high level of heterozygosity; the inbreeding process has deleterious effects on most cross-pollinated species.

Problems of Seed Production in Forage Crops

Most forage crops are cross-pollinated, either by insects or wind. Most forage varieties are populations of different, highly heterozygous genotypes assembled by the breeder in a delicate equilibrium. This equilibrium between genotypes is very important; because it is

associated with the particular makeup of each variety, it must be maintained during the lifetime of that variety.

Before dealing with the genetic and agronomic problems of seed production in cross-pollinated forage crops, it is important to note that forage crops are bred and grown to maximize the production of leaves; in other crops, such as cereals, pulses, and oil plants, seed production is, biologically speaking, synonymous with grain production.

Problems in maintaining varietal integrity

The main problems in maintaining varieties of cross-pollinated species--those that are, genetically speaking, in equilibrium--are isolation, generation of multiplication, and seed production outside the area of adaptation.

These problems all relate to the necessity that a variety be distinct, uniform, and stable. Indeed, the certified seed of a variety cannot be legally marketed in many countries unless it has these characteristics. Even in countries without seed laws, these requirements should be met in the interest of farmers. Seed companies or private plant breeders may complain that excess regulation of seed production and marketing hamper agricultural progress, but carefully-written laws are vital to prevent fraud, particularly when dealing with cross-pollinated crops in which varietal identification is biologically difficult.

a. Isolation

Isolation is necessary to prevent outcrossing with foreign pollen and consequent changes in gene frequencies and, ultimately, in the genetic properties of a variety. For producing breeder seed, mechanical isolation with mesh or special pollen-proof glasshouses can be used, but seed production under those conditions is often limited and therefore not economical.

Wind-pollinated forage crops can also be isolated by growing them in relatively small plots bordered by another crop which creates a physical barrier to foreign pollen. Heavy cloth bags are another efficient way to isolate varieties of the same species. When wind is the main pollination agent, prevailing wind direction must be considered when laying out seed production plots sown with different varieties of the same species. Because of economic limitations on using physical isolation, spatial isolation is more commonly used, and minimum distances are required at different stages of seed multiplication.

The degree of outcrossing which actually occurs in a seed crop is influenced by the protective effect of pollen released by the variety itself. Griffiths (1952), working with perennial ryegrass (*Lolium*

perenne), found that intervening plants of the same variety had a marked buffer action and reduced contamination more effectively than spatial isolation (see Table 1).

Table 1. Percentage of contamination in non red-base perennial ryegrass plants at varying isolation distances.

Distance from contaminant (m)	% Contamination		
	First row	Sixth row	Average of six rows
7.5	41.63	17.86	27.15
15.0	12.09	4.79	7.21
30.0	5.60	1.65	3.73
60.0	1.81	0.56	0.89
120.0	0.81	0.59	0.52

The size of a seed field is another important factor affecting contamination. Increasing the size reduces the effect of intervarietal outcrossing. In either wind- or insect-pollinated crops, the smaller the seed field is in relation to the contaminant, the greater the chance of crossing. Thus, the isolation requirements for producing different classes of certified seed of cross-pollinated legumes vary with field size, as shown in Table 2.

Table 2. Minimum isolation requirements for production of alfalfa, birdsfoot trefoil, and red and white clover seed.

Seed class	Field size	
	<5 acres (<2.5 hectares)	⩾5 acres (⩾2.5 hectares)
Foundation	400 m	400 m
Registered	200 m	100 m
Certified	100 m	50 m

Isolation is also very important in producing certified seed in farmers' fields, but is more difficult to create under such conditions. A farmer who attempts to grow a crop for seed production under contract can have his efforts wiped out by a neighboring farmer who plants the same crop. Laws in some countries such as France and the UK dictate that crop choice in specific areas must be controlled by local authorities.

b. Number of generations of multiplication

The number of generations of multiplication must be kept to a minimum to prevent or reduce the amount of genetic change. In practice, during the generations of multiplication, the population is affected by differences in climate which may change genetic frequencies over a number of generations. The genetic properties of a population also change because different plants produce different seed yields. In forage grasses, for example, a "leafy" type produces less seed than a "stemmy" type, and during many generations of multiplication, the first type can be transformed slowly into the second. In the case of synthetic varieties that are based on a number of selected mother plants, vegetative propagation of mother plants is used to obtain the breeder (or pre-basic) seed. The amount of this seed is usually limited and it is maintained for long-term storage in moisture-proof containers at 0°C. This first generation seed is used over a period of years to produce basic seed, and then after two more generations, certified seed. The number of generations is thus kept at three, which is possible only with very large-scale vegetative propagation of mother plants. When the demand for a variety increases, higher seed production is achieved by increasing the area for the production of breeder seed, and not by adding one or more generations of multiplication.

c. Seed production outside the area of adaptation

Strictly speaking, this problem of variety maintenance refers to multiplication of new varieties in areas other than those for which the variety was developed. However, similar problems are encountered with the importation of varieties developed in a different country.

As many examples show, rapid agricultural progress has resulted from transferring varieties developed in one area to new areas. The importation of seed from different countries may have other, detrimental consequences, however depending upon the species and country of origin. For some species, the movement of certified seed from one country to another may lead to:

- disease problems that often did not occur in the country of origin.
- such a great increase in variability between individuals that a population is no longer uniform enough to be called a variety.

This is particularly true of some cross-pollinated crops, such as perennial forage crops, in which uniformity is strictly associated with adaptation. A population that is "relatively" uniform in its area of adaptation may become highly variable when grown under different climatic conditions.

- reduced persistence of perennial species due to lack of adaptation.
- a form of genetic erosion, in which the release of unadapted material directly to farmers creates a genetic flow into the adapted populations; the consequence is that future germplasm expeditions will no longer sample native material.

These dangers can be avoided only by creating a testing system that applies to new varieties as well as to any imported variety.

Countries in which climatic conditions do not allow seed production may breed their own varieties and produce certified seed outside the area of adaptation of the new variety, even in foreign countries where climatic conditions are more favorable. The procedures for growing certified seed outside a variety's region of adaptation protect varietal purity by limiting the number of generations of increase and the number of seed crops that can be harvested from a field.

Another consideration is that when seed of grass and legume varieties is produced in different environments, selective pressures may cause genetic shifts of such magnitude as to affect varietal performance. The amount of genetic shift depends on the number of generations of increase, management practices, and climatic difference between regions of seed production and the area where a variety was developed. Variations in plant height and percentage of winter injury in different seed lots of the alfalfa variety Range have been related to locations of seed production (Smith 1955). Seed lots produced in the southern USA showed a definite trend toward more taller plants and greater winter injury. Similar findings have been reported for the alfalfa varieties Narragansett and Vernal when seed was grown in Mexico under short days. On the other hand, seed lots grown in Alaska and Canada produced fewer tall plants but a greater number of shorter ones with a rosette growth habit. Another example is the ladino clover variety Pilgrim, of which 21 parental clones exhibited a wide range in earliness and persistence of flowering--a variability that was greatest under shorter daylengths. Under such conditions, the clones would contribute disproportionately to this synthetic variety.

Management practices can also alter the genetic complex of an open-pollinated grass or legume variety during seed production. Changes in the proportions of plant types were observed in the red clover variety Lasalle when seed was harvested the first spring after planting. There was a significant increase in the number of early-flowering types and a corresponding decrease in the proportion of late-flowering or non-flowering plants.

For perennial species which can produce seed for many years, the seed should be harvested only from the first year after sowing, because differential survival in subsequent years may sensibly affect the genetic contribution of individual plants.

Although certified seed can be successfully produced outside the area of adaptation, genetic stability and varietal performance can best be maintained when seed is produced in the environment where the variety was developed. Basic seed, therefore, should always be produced within the adaptation area.

Agronomic problems of seed production

Forage crops have been selected primarily for their ability to produce a large amount of dry matter, so agronomic practices for seed production in a given forage crop often differ greatly from those used for the same crop grown for forage production. Row planting, for example, has been shown to increase seed production more than dense planting in many forage crops. Economically speaking, a forage species' seed crop can be more profitable than forage yield. Agronomic practices such as irrigation and heavy fertilizer use--possibly not justified when a given species is grown for forage production--are commonly used to increase seed production.

Forage grasses and legumes are grown for seed under a great variety of climatic and soil conditions, and each species has specific agronomic requirements. Only the following very general guidelines can thus be given for planting, growing, and harvesting a seed crop.

Date of seeding: When grasses and legumes are sown for seed production, the dates of seeding are those that usually give the best forage stands.

Rate of seeding: Generally, in grasses, 25 viable seeds per foot (1 seed/cm) are adequate and one established plant per foot (or one plant/30 cm) gives enough of a stand to produce maximum yields. Most legume crops have lower optimum seeding rates when grown for seed than for forage.

Solid versus row planting: Row planting is widely recognized as better than solid planting to maximize seed production in many forage crops. Row planting has several advantages: less stock seed is required per hectare, weed control and rogueing are simplified, and many species produce seed at a higher level for a longer time.

Fertilization: Favorable levels of fertility are essential for consistently successful production of grass and legume seeds. Moderate to heavy applications of nitrogen are required for economical production of grass seed. Legume crops, whether grown for seed or forage, have the same general nutrition requirements. Application of minor elements such as boron and manganese is often required to keep the plant in the best condition for seed production.

Pollination: For insect-pollinated forage crop such as alfalfa, pollination is a key factor for successful seed production. All factors that result in an abundance of actively-pollinating insects *will* also favor good seed production. In the alfalfa seed production area of the United States, as many as 8 to 10 bee colonies per hectare are commonly employed during full-bloom.

Harvesting: This is one of the most critical steps in forage crop seed production. Although seed viability is attained in some species 7 to 13 days after anthesis, the seed has a high moisture content and a low 1000-seed weight at this time. If harvested at this stage, respiration by the seed during storage may produce enough heat to reduce viability. On the other hand, as harvesting is delayed, losses from seed shattering can increase to 70% in some species. Early lodging also contributes to reduced seed yield; it has been shown recently that chemical application to prevent lodging in some forage grasses has increased seed yield up to 50%, mainly because the crop was able to divert a greater proportion of total dry matter yield into seed production.

Since 1950, the use of desiccants as pre-harvest sprays has considerably aided seed growers in overcoming some harvesting hazards. These sprays cause the foliage to wilt and dry out rapidly enough to permit harvesting before the pods or heads have dried enough to shatter the seeds.

Seed losses due to shattering may also be prevented by selection for high seed retention capacity. Although genotypes with the ability to retain seed have been identified in some species, this problem has generally received little attention.

Post-harvest treatments: Burning, clipping, or grazing affect the seed yield of forage grasses. Burning stubble and straw has given excellent control of several foliar, inflorescence, and seed-borne diseases. In some species, summer burning stimulated the number of fertile tillers and greatly increased seed yields. Clipping and grazing are commonly employed after harvest of grass seed crops, although they often have a negative effect on seed yield.

Weed control: This is essential to produce strong healthy plants. Weeds established in a seed crop not only compete with the sown crop for moisture, nutrients, and light, but may also lead to the rejection of a seed lot for commercial use because of contamination by weed seed. Many weed seeds are physically similar to crop seeds, and their removal is difficult, if not impossible. Efficient weed control, therefore, must start with the selection of fields relatively free of weeds, and continue until the crop is harvested and processed for marketing.

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Seed Production in Forage Crops With Special Emphasis on Self-Pollinated Species

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Seed production in forage crops is a complex process, because the diverse species have different genetic compositions and often have different agronomic requirements for seed production as well. These species can be grouped as follows:

Vegetatively-propagated species: Some forage species or cultivars are propagated vegetatively, such as napier grass (*Pennisetum purpureum*). A variety multiplied in this manner is expected to reflect only environmental variability, except when mutation takes place. Propagation of these varieties does not pose genetic problems, but is expensive, and disease problems must be taken into account.

Self-pollinated species: Genetically, these result in a pure line, which is the progeny obtained by selfing a homozygous plant. Theoretically, such a variety behaves like a vegetatively-propagated cultivar (clone), differing only because the genotypes of a pure line are all homozygous, while those of a clone may be either homozygous or heterozygous. Problems exist due to mutation and/or during selection and multiplication.

Cross-pollinated species: These are characterized by genetic variability within the population; the type of mating system leads to a high level of heterozygosity. (Cross-pollination is discussed elsewhere in this book.)

Another problem of forage seed production is that forages are selected mainly for their ability to produce high dry matter (DM)

yield, whereas seed yield might require different selection. Agronomic practices for seed production thus often differ greatly from those for forage production in the same crop, as shown in Table 1.

Table 1. Differences in agronomic practices for seed and forage production.

Treatment	Forage production	Seed production
Plant population	Dense	Light
High fertilizer, irrigation, and herbicide application	Less justifiable	More justifiable due to high economic return
Weeding	Some weeds may be accepted if palatable	Essential to maintain seed purity regardless of weed type
Row planting	Not essential	Essential to allow weeding

In addition, a forage crop grown for seed, especially a legume, might require additional inputs; for example, provision of insect pollinators might be necessary to maximize seed yield in some legume species/cultivars because of high natural crossing, low automatic selfing, or low self-fertilization. Bohart (1960) summarized the fertility and pollination characteristics of some forage legumes (Table 2).

Feed shortage and natural rangeland

Natural rangelands in the Middle East and North Africa historically provided 70-80% of animal feed (FAO 1972). During the past two decades, however, these natural resources have suffered great deterioration which has made them unable to contribute to the animal feed requirement as before.

At present, the feed shortage is most acute during late summer and early winter months (Fig. 1). Animals should leave the cropping area during the time of feed shortage, go to the natural rangelands, and stay there until crop harvest. Only then should they be allowed to return to cropping areas to feed on crop residues.

One remedy for the feed shortage, which would also have a favorable impact on natural rangelands, is to encourage intensive forage and pasture production on available arable land. Farmers in the region grow winter cereals in a two-year rotation (cereal/fallow). They crop

Table 2. Fertility and pollination characteristics of some forage legumes*.

Genus/species	Natural crossing	Self-fertility	Auto self-pollination
Trifolium			
incarnatum	high	high	low
pratense	high	low	low
repens (white)	high	low	low
repens (ladino)	high	low	low
hybridum	high	low	low
Medicago			
sativa	high	low	low
falcata	high	low	low
lupulina	low	high	high
Melilotus			
alba	high	high	moderate
officinalis	high	low	low
indica	moderate	high	high
Vicia			
vilosa	high	high?	low?
sativa	low	high	high
atropurpurea	low	high	high
Lespedeza			
Annual spp.	low	high	high
Perennial spp.	high	low	low
Lotus			
corniculatus	high	low	low

*Source: Bohart 1960.

about 50% of the available arable land annually, leaving the rest--more than 35 million ha--as fallow each year.

Suitable forages, especially legumes, can be grown to produce animal feed. Some of these legumes are more suitable for hay production, such as vetches and peas, while others are more suitable for grazing, such as annual medic.

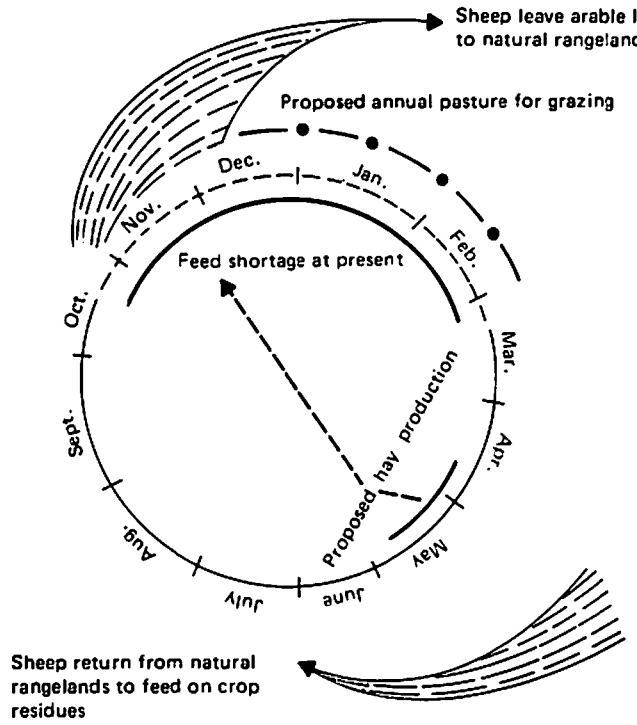

Fig. 1. Annual cycle of sheep movement and feed supply.

Medic pasture and seed production

Annual medic is a pasture crop developed to be grown alternately with cereals to provide pasture every other year (Fig. 2).

The process of producing seed for annual medic begins by choosing an adapted species that will fit into the cereal/medic farming system. Important characters include:

1. Suitable dormancy during the cereal phase of the rotation (second year) to avoid excessive medic germination.
2. Adaptation to climatic and soil conditions, including ability to nodulate and fix atmospheric nitrogen.
3. Freedom from diseases.
4. High seed production to build up sufficient seed reserve in the soil for future regeneration.

Medic seeds are small-sized, so field choice, land preparation, planting, and harvesting should take this into consideration.

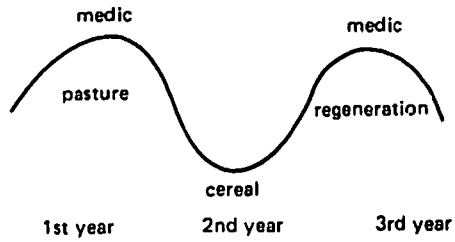

Fig. 2. Annual medic/cereal rotation.

Soil type

Medic is adapted to neutral-alkaline soils, but heavy, cracking soils make harvesting difficult, since many pods fall into the cracks.

Land preparation

Land must be well-levelled and weed-free, which can be ensured by plowing and levelling operations early in the season.

Planting

In northern Syria, planting takes place after the first rain (in November), when enough soil moisture exists to facilitate quick seed germination. Shallow planting at 1-2 cm soil depth, essential for medic, can be achieved by adjusting the seed drill to the desired planting depth. Seed broadcast and rolling can also allow shallow planting, but row planting is preferred to facilitate weeding operations later.

Fertilizer application

Soils must either be naturally rich in all essential nutrients, or fertilized. Soils of the Middle East and North Africa have a well-known phosphorus deficiency, which can be corrected by applying 40-60 kg P_2O_5/ha at the time of medic sowing.

Seed inoculation

In areas where medic is to be grown for the first time, seed inoculation with appropriate rhizobia is important to ensure good crop establishment.

Grazing

Depending on the season and crop establishment, the medic crop may be lightly grazed by sheep early in the season, but grazing must be stopped as soon as the crop begins to flower.

Weed control

Hand weeding and inter-row cultivation may be done, and suitable herbicides such as grass killers may be applied when appropriate to

Fig. 3. A field of medic.

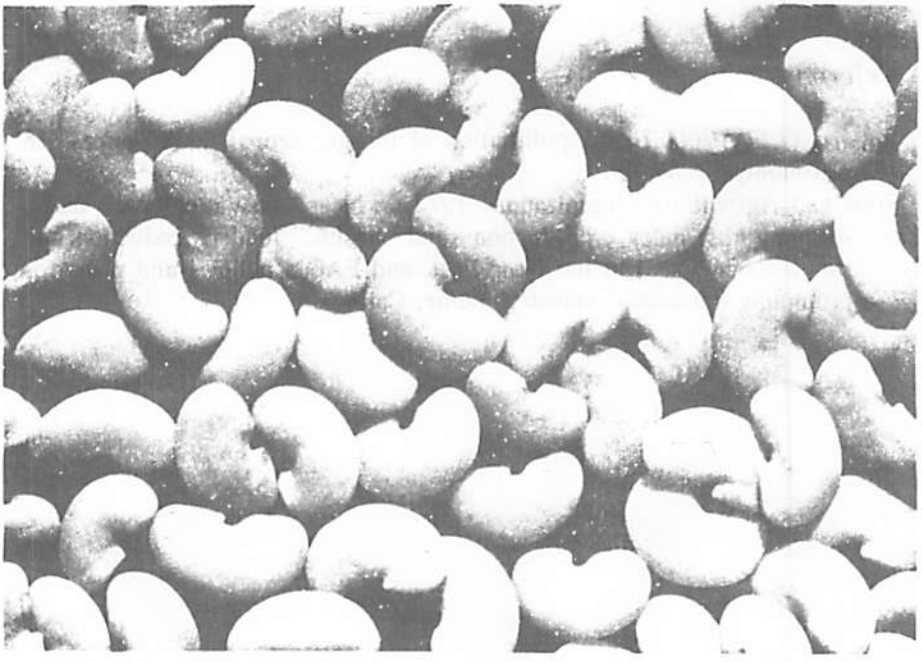

Fig. 4. Medic seeds.

suppress weed populations. Weeds compete with the crop for moisture and nutrients, and weed and medic seeds harvested together are difficult to separate because of their small size.

Harvest

At time of harvest when all plant parts are sufficiently dry, the trash (tibin), consisting of dry branches and twigs, is harvested with a tractor-mounted side mower. Hand-push machines with reciprocating blades can be used for small areas, which also helps to make pods drop to the ground.

Rolling

After harvesting, a suitable roller is dragged over the crop, which helps pod-shedding and levels the land for easier pod collection.

Pod threshing

In small plots, pods can be swept, collected, and threshed in three different steps. For large areas of commercial production, a combine medic harvester such as Harwood Bagshaw, a commercially-designed machine, can sweep (by suction), collect, thresh, and clean the seeds in one operation. A 10 ha field can be harvested in five hours. The machine must be thoroughly cleaned to avoid seed mixing before harvesting a new cultivar.

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List of Useful Publications for Seed Technologists

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Many of the publications of the international organizations are available in several languages.

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