Physics with Industry workshop 2022
Title: Eavesdrop on Seeds

1. Company information

Bejo is one of the leading companies regarding the breeding, production and sales of vegetable seeds. Globally 2000 employees are working at Bejo. Their primary Research and Business facilities are located in Warmenhuizen, the Netherlands, but they have sales/distribution offices and breeding facilities all over the world. Their key business objective is the breeding of high quality food crops emerging from high quality seeds. By combining state of the art seed processing and seed treatments Bejo offers a wide range of products where quality has the highest priority. Bejo's main crops are *Brassica* (cabbage), *Daucus carota* (carrot), *Beta vulgaris* (red beet) and *Allium* (onion and garlic).

2. Problem

In a changing world food availability is an increasing concern and a crucial priority. The supply of high quality seeds at an affordable price is needed to meet food demands in the 21st century. To meet these demands Bejo, and other seed companies, require next-generation state-of-the-art and high through-put seed quality assessment tools to increase their seed production efficiency and durability, supply chain efficiency and to guarantee food produce for fair prices in the decades to come.
4000 seed lots (up to 600 kilos which translates to millions of seeds per lot) arrive at our warehouse in Warmenhuizen each year. These seeds need to undergo several cleaning and grading steps to finally yield a high-quality sellable product. Generally, the seeds need to be cleaned (removal of dirt and non-seeds), calibrated, coated and packaged. Calibration entails the passing of seeds lots over big sieves to remove low-quality seeds based on seed diameter. To track seed quality upgrading during the whole process 120.000 seed quality assays per year are performed by the Bejo Seed Analysis and Seed Health laboratories. Most of these assays require careful examination and scoring of germination and plant growth, which until recently was mostly done manually and visually. Growing demands, diversification of crops and company growth forecast an increase in test requests and Bejo is, therefore, investing in image analysis, robotics and AI in order to increase capacity, efficiency and reliability of those tests.
Until now the development of tools to monitor seed germination and seedling growth are based on image analysis. These tools depend on changes in shape and colour (as a result of the appearance or growth of the radicle and the shoot) but have shown to be error prone, due to interference of neighbouring seeds. An advantage of methods based on image analysis is that seeds are individually tracked. However, this tracking of individual seeds is not always essential. Assessment of germination characteristics of the population (batch) is usually enough.
Many seeds exhibit photo-inhibition, i.e. reduced germination potential in white light, or the reverse; failure to germinate in the dark. Especially the latter can be detrimental to seed germination in soil, for obvious reasons. An important fraction of our germination test capacity is usurped by dark germination tests. Image analysis to track germination of seeds in the dark is very difficult, as most visible wavelengths will trigger seed germination. Using sound to detect germination would dispense any requirement for active illumination and allow automation of dark germination tests.
As detection of germination by microphones does not require an illumination source no heat would be generated in the germination chamber yielding a more energy efficient and environment friendly method. Cooling equipment to remove the heat produced by light sources for imaging would no longer be required.
Pilot experiments with RGB-imaging also revealed that seed segmentation requires a lot of effort as seeds, both within and between crops types, exhibit substantial variation in color and shape. For instance, Bejo biological seeds carry a white coating and it can be imagined that detection of white radicles protruding from such seeds are hard to reliable detect in an automated way.
Potential pragmatic advantages aside, we also envision that signal processing/analysis of sound recordings during germination could reveal physical and/or physiological information about the seed(s). Potentially, these signals could encode a new and hitherto unexplored marker for seed quality, advancing the seed physiology field not only

industrially, but also opening up new avenues for academic research.

Seeds consist of an embryo, which are encapsulated by an outermost seed coat and an underlying endosperm.

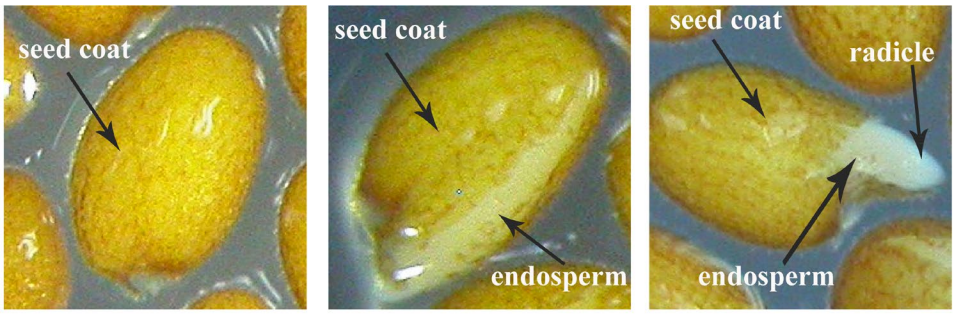

Figure 1. Three stages of germination of Arabidopsis seeds. Left panel: fully imbibed seed just before seed coat rupture. Middle panel: Seed coat rupture, radicle tip still enveloped by the endosperm. Right panel: Endosperm rupture: radicle exposed. (Figure from Zhong *et al.*, 2016)

Germination is characterized by two events; rupture of the outer seed coat and, subsequently rupture of the endosperm, which allows the radicle (embryonic root) and shoot to emergence from the seed (Fig.1).
We wonder if gemination can be detected by sound produced by the rupture of the two enveloping tissues of the seed and thus if a germination monitoring system could be developed based on monitoring of these sounds. Such a system would allow continuous monitoring of the seeds and enable the construction of detailed and high resolution germination curves (Fig.2). Such curves are essential to determine the quality of the seeds.
Throughput-wise we assume a two tiered-approach: i) low-throughput initially for exploration of optimal setup (germination conditions; usually on wet paper allowing unperturbed sound detection) and signal processing, and ii) scaling-up to a high-throughput method if i) shows potential.
At this workshop we would like to raise the question if germination of seeds can be scored by listening to the seeds at infrasound, audible or ultrasound frequencies and if this could be developed into a simple implementable acoustic system for seed germination assessment.

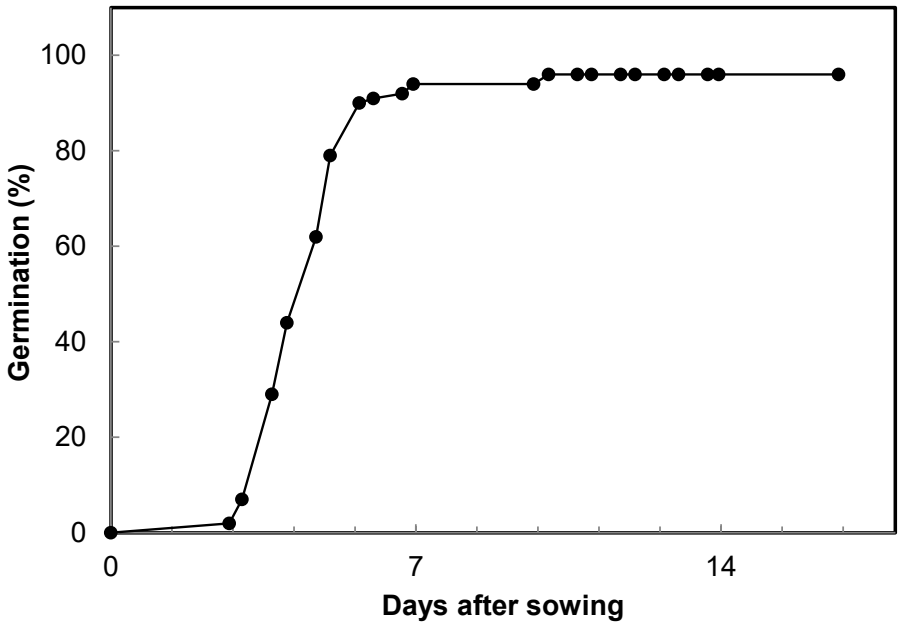

Figure 2. A typical germination curve obtained by visually inspecting the seeds on a germination plate. Seeds were placed on wet filter paper in a closed box and germinated. Seeds were scored regularly. Notice the gaps in the observations due to the weekend during which human observers are not available.