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Cuvillier Verlag Göttingen

https://cuvillier.de/de/shop/publications/3322

1. INTRODUCTION

Seed is a basic requirement for food production and for establishing food security to farmers, especially resource-poor ones (FAO, 1999). In this regard, the role of seed is two-fold: as germplasm and as agricultural input. As germplasm, seeds are raw materials that can be stored and manipulated to design plants for specific purposes and needs (Wilkes, 1992; Dudnik *et al*., 2001). In food production, seed is the only living input that responds to stimuli in quantifiable measures. But in addition to being alive, seed must also possess those qualities that allow rapid germination and seedling establishment because the vigour of the resultant seedlings and consequently, the level of harvest obtained at the end of the season, depend on the quality of seed planted (Feistritzer, 1975; Cardwell, 1984). As agricultural input therefore, seed is the biological embodiment of all production potentials, setting the limit of the level of responsiveness to environmental and agronomic factors including inputs like fertilisers.

There is a high level of awareness among different stakeholders about the importance of seed quality. For example, farmers in Mexico prefer flat to round maize seeds because flat seeds have better quality and field performance (Batistella *et al.*, 2002). Seed, therefore, is no longer a volume commodity sold on the basis of weight but a living entity marketed and purchased on the basis of number of pure, viable and germinable seeds in a lot (Beavis and Harty, 1999). Traditional farmers do not just use any germinable material; instead, different criteria and combinations of physical characteristics are employed to 'select' seeds that show potential of producing good crop. In modern agriculture, seed production has become highly specialized and seed certification is mandatory in some countries in order to ensure that marketed seeds are of the highest possible quality (Hill *et al.*, 1997).

The factors that guarantee production of high quality seed from year to year are not yet fully understood (Coolbear *et al.*, 1997; Hampton, 2002), but that seed maturity and post-harvest handling affect seed quality and seedling vigour is well known (Maguire, 1977; Cardwell, 1984; Bennett *et al.*, 1988; Dornbos, 1995a, b). Harrington (1972) proposed that maximum seed quality is attained at the time a developing seed reaches its maximum dry weight, normally referred to as physiological maturity, PM (Egli, 1998), and that quality declines thereafter. Since then, agronomists and commercial seed producers have used this hypothesis as the basis for making harvest decisions in seed production (Knittle and Burris, 1976; Brooking, 1990; Dornbos, 1995a; Egli, 1998). But in the recent past, physiologists contend that the hypothesis is misleading when considering seed storage physiology (Ellis and Pieta Filho, 1992; Coolbear, 1995). Therefore, there is no agreement on the best time to harvest seed crop and the best indicator for assessing seed quality (Ellis and Roberts, 1980a; TeKrony and Egli, 1997; Ellis *et al.*, 2000). But contrary to Harrington's hypothesis, there is indeed ample evidence in many crops, for example wheat (Rasyad *et al.*, 1990; Ellis and Pieta Filho, 1992), beans (Chamma *et al.*, 1990; Coste *et al.,* 2001), millets (Rai and Hanna, 1997) and maize (TeKrony and Egli, 1997; Ajayi and Fakorede, 2000; Vieira *et al.*, 1995; Faria *et al.*, 2002), showing that the relationship between seed dry weight and quality is crop-specific. But in all the studies to date, there has been very little attempt to identify the reason(s) for the differences, sometimes within a botanical family, in the relationship between seed dry weight and quality.

There is a wide gap in the understanding of seed quality with respect to biochemical as opposed to morphological events during seed development and agronomic factors in seed production. Much of the research on seed development and maturation has been aimed at understanding either the physiological basis of crop yield and pathways for yield improvement (Jones and Simmons, 1983; Jenner *et al.*, 1991; Egli, 1998; Westgate and Boote, 2000) or plant developmental biology (Galau *et al*., 1991; Bewley and Black, 1994; Goldberg *et al.*, 1994; Larkins and Vasil, 1997; Weber *et al.,* 1998). Therefore, the main focus was on processes involved in the production of the materials that eventually make up yield and other nutritional and industrial uses to which seeds are put with less emphasis on how these materials are utilized by a seed to sustain its life and express its quality (Lopes and Larkins, 1993; Egli, 1994).

The physiology and biochemistry of seed development are well documented (Khan, 1982; Bewley and Black, 1994; Kigel and Galili, 1995; Egli, 1998). But "much of this information is rudimentary and inadequate understanding of the biology of seed development remains a major challenge" (Jones, 1994). Studies relating physiological and biochemical changes to the concurrent changes in seed quality during maturation and storage are rare (Gray and Thomas, 1982; Coolbear *et al.*, 1997). Hill *et al.* (1997) aptly described this gap as follows:

> "The most obvious conclusion about much of the research on seed quality must be that it is generally inconclusive…Quite a lot is known about seed quality- we trade on it, we research it and we pay reverence to it. What we really need, however, is a clearer and more precise understanding of why and how seeds loose quality on the plant, at harvest, during processing and during storage, and to take into account the interactions between different storage conditions and seed's prestorage history. Such an approach to the term 'seed quality' would give us clearer ideas on how to more fairly assess the planting value of seeds prior to sowing", pp 236.

Therefore, the aim of this study is to describe the development of maize seed quality during maturation from both physiological and biochemical perspectives and its loss during post-harvest operations and storage. The **objectives**, as research questions, are as follows:

i. how are changes in maize seed dry weight and biochemical composition related to changes in physiological and storage seed qualities during maturation?
ii. which operation(s) in the harvesting and post-harvesting stepwise mechanical seed processing operations is (are) the most critical to loss of seed quality through mechanical damage?
iii. how do storage temperature and duration affect the above relationships? and
iv. how does seed quality affect successful seedling establishment in the field?

Maize was chosen for this study because it is the most widely adapted crop grown throughout the world under a wide range of climates (Maiti and Wesche-Ebeling, 1998; Paliwal and Smith, 2002). From the viewpoint of seed technology, agronomy, genetics, physiology, and biochemistry, it is a model experimental crop that has been studied extensively (Maguire, 1977; Sheridan, 1982; Watson and Ramstad, 1987; Dumas and Mogensen, 1993). It was the model plant for early works on seed development and reserve accumulation (Dure, 1975; Morris, 1997). Its high multiplication ratio (Zscheischler *et al*., 1990; Vega *et al.,* 2001) also makes it suitable for large-scale seed production purposes.

2. LITERATURE REVIEW

2.1 Meaning of '*seed quality*'

The phrase '*seed quality*' has different meanings across scientific disciplines. But from an agronomic perspective, quality encompasses physical, biological, pathological and genetical seed parameters that ultimately have a bearing on plant performance and final yield of a crop in the farmers' fields (Esbo, 1980; Ellis, 1992; Burris *et al.*, 2002; Hampton 2002). High quality seeds are specifically bred and genetically pure; they are free from disease, vigorous, and high in germination percentage (Basra, 1995).

Some of the components that add up to seed quality are 1) ***genetic quality***: an indicator of the inherent abilities of a seed coded in the embryo and, on another hand, it refers to the distinctiveness, uniformity and stability of a given cultivar (McDonald, 1998; Smith and Register, 1998); 2) ***physiological quality***: an index of the levels of viability and of vigour (Hampton, 1995; Louwaars and Marrewijk, 1996; Kelly and George, 1998); 3) ***storage quality***: an indicator of the inherent ability to maintain viability, vigour potential and other quality components during storage (Delouche and Baskin, 1973; Roberts, 1973; Ellis and Roberts, 1980b; Ellis, 1991); 4) ***mechanical quality***: the ability of a seed to withstand stress and damage without significant loss of quality while passing through different machines during harvesting and post-harvest processing (Boyd *et al.,* 1975; Burris, 1979; Hill and Hill, 1995; Cicero *et al.*, 1998; Hill *et al.,* 1999a); 5) ***health quality***: an index used to assess seed hygiene, indicating the extent to which the seed is free from infection and infestation by diseases and pests (Berjak *et al*., 1986; Doehlert *et al*., 1994; Kulik, 1995; McGee, 2000); 6) ***analytical quality***: a measure of the physical purity of a seed lot, usually of grain crops (Copeland and McDonald, 1995; Kelly and George, 1998); 7) ***physical quality or eye-appeal***: a combination of physical attributes such as width, thickness, length, shape, size, colour, and density of a seed (Boyd *et al.*, 1975; Linnett, 1999), and 8) ***seed lot uniformity***: a property of seed lots (Hampton and Kåhre, 1994).

2.2 Development of seed quality

2.2.1 Maize seed development and maturation

Botanically, maize seed is a one-seeded fruit in which the seed is permanently enclosed in the adhering pericarp (Kiesselbach, 1999). However, it is a widely accepted practice to refer to the fruit of the family *Poaceae*, to which maize belongs, as seed (Coolbear *et al.*, 1997; Egli, 1998). 'Kernel', 'grain' and 'seed' are also often used interchangeably (Preiss and Sivak, 1996). Maize seed comprises of three major parts: pericarp (6-7%), the endosperm (80-84%) and the embryo

(10-13%) (Singletary and Below, 1989; Zscheischler *et al.*, 1990; Doehlert and Lambert, 1991). Each of these parts has distinct genetic origin (Harris *et al.*, 1993; Boesewinkel and Bouman, 1995).

The development of maize seed is similar to the general pattern for many other botanical seeds (West and Harada, 1993; Bewley and Black, 1994; Goldberg *et al.*, 1994; Kigel and Galili, 1995). Salvador and Pearce (1994) described four physiological phases of maize seed development as dilatory, exponential, linear fill and attenuative phases. During the dilatory phase accumulation of dry matter is slow and all fertilized ovules are regarded as incipient seeds. A short exponential phase follows when normal seeds initiate rapid development; this phase is usually an inflection in the plot of aggregate dry matter accumulation. After this, a relatively longer period of effective filling or the linear fill is the period when most of the reserve materials are accumulated. Lastly, the attenuative phase denotes the period when metabolic activities slow down as a result of desiccation and termination of accumulation of reserve materials. This pattern of accumulation is independent of both genotype and environment (Jones and Simmons, 1983; Wilson and Trawatha, 1991; Westgate, 1994; Ajayi and Fakorede, 2000).

Filling of developing maize seeds occurs as the reserves, principally starch, are deposited within the endosperm. Usually, the developing endosperm accounts for most of the seed weight increase with the testa-pericarp weighing somewhat less, and the embryo weight almost negligible (Dure, 1975; Kowles and Phillips, 1988; Zamski, 1995; Weber *et al.*, 1998). The endosperm accumulates primarily starch, whereas the embryo accumulates high concentrations of oil (Doehlert, 1990). Doehlert and Lambert (1991) observed variation in rates and composition at various stages of seed development. Agronomic (Zhang *et al*., 1994; Saayman and Venter, 1996; Yadav and Singh, 2000), genetic (Feil *et al.,* 1990; Jones *et al.*, 1996; Letchworth and Lambert, 1998; Bulant *et al.,* 2000), physiological (Doehlert and Kuo, 1990; Doehlert *et al.*, 1993; Wilson and Mohan, 1998) and environmental (Fenner, 1992) factors affect synthesis and accumulation of maize seed reserves.

2.2.2 Composition of mature maize seed

The approximate biochemical composition of mature (whole) seed of a normal maize genotype is 80% carbohydrate (mainly starch), 10% protein and 5% oil; endosperm plus aleurone layer contain approximately 88% starch, 7% protein and <1% oil while the embryo contains roughly 9% starch, 19% protein and 31% oil (Doehlert, 1990; Shewry and Tatham, 1990; Bewley and Black, 1994). Maize seed contain five times N, half Mg and one-tenth Ca