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Viability of the Seedball Technology to Improve Pearl Millet Seedlings Establishment Under Sahelian Conditions - A Review of Pre-Requisites and Environmental Conditions

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***Abstract* – Poor and erratic rainfall, poor chemical soil fertility and low water holding capacity of widely spread sandy soils are major constraints in the pearl millet (*Pennisetum glaucum* (L.) R. Brown) cropping system of the West African Sahel. These factors lead to poor seedlings germination and vigour, and in turn low yields. Since the early growth stages determine final crop performance under Sahelian conditions, improvements should focus on this time span critical for final crop performance. Lack of financial resources and skills often prevent Sahelian farmers from adopting many of the existing solutions to improve crop performance such as seed treatments, mineral fertiliser and application of irrigation. Due to short growing period and labour constraints at sowing, Sahelian farmers partly practise dry sowing. However, this practice is associated with a high risk of crop failure due to regularly occurring early droughts. Re-sowing might then be constrained by seed and labour availability. Urgently needed is a cheap technology based on locally available resources that reduces seed needs, increases early seedling vigour and reduces the crop failure risk. Seedball might be such a technology. Seedball is an easy and affordable "seed-pelleting" technique that combines indigenous local materials such as sand, loam, water and seeds in a gravimetric ratio to enhance seedling establishment. Amendments such as fertiliser or pesticides can be added depending on target preferences and local problems. Our evaluation shows that seedballs have the potential to improve the Sahelian pearl millet cropping systems since the technology is mainly based on local resources and thus, can be adapted to local needs by individuals through added nutrient additives such as mineral fertilisers and wood ash. Additionally, seedball production does not conflict with other pre-seasonal labour loads or gender issues, and is coupled with low financial demands.**

***Keywords* – Dry Planting, Dry Sowing, Germination Constraints, Local Resources, Seedling Emergence, Seedling Vigour.**

I. INTRODUCTION

In the West African Sahel, pearl millet (*Pennisetum glaucum* (L.) R. Brown) is the major staple crop, mainly produced on *Arenosols* [1] that are low in both available nitrogen (N) and phosphorus (P) [2]. Millet yields are severely constrained by the combined effects of low and variable rainfall [3, 4], low soil chemical fertility [5] as well as financial and labour scarcity [6]. One farmer adaption strategy to these difficult conditions is dry planting [7], in particular for remote fields. However, this strategy bears a very high risk of crop failure due to early droughts that regularly occur and lead to poor seedlings emergence and sometimes, total crop loss [8]. Consequently, farmers need to replant but are often faced with seed and labour shortages due to restricted financial resources [6]. Innovative options that can improve Sahelian pearl millet-cropping system comprise seed coating [9], fertiliser placement [10, 11], irrigation systems [12] or mineral fertiliser [13, 14]. Nonetheless, these options are often unaffordable for subsistence farmers or simply not in spatial reach. For example, the sophisticated machine used for P coating of pearl millet to increase panicle yield [9] necessitates high financial inputs. Additionally, mineral fertilisers are often not accessible on the local markets. As a consequence of lacking financial resources [6], skills [15] and dysfunctional markets, resource poor and illiterate farmers are doomed to deal with poor pearl millet performance on repeatedly cropped *Arenosols*.

In designing and introducing agricultural innovations especially for African farmers, utilisation of information depends on education and literacy level [16], which most Sahelian farmers lack. Particularly when focusing on poor subsistence farmers, management options need to be simple and based on cheap local materials. One such option is the seedball technology. It was developed by Masanobu Fukuoka within the permacropping approach to improve rice performance in dry fields [17]. Seedballs are produced using a gravimetric mixture of soil materials, additives that mainly serve as nutrient sources, and several seeds. They usually have around 2 cm diameter size, can be easily produced by hand during times of low workload in the off-season, rely on indigenous local resources, and are cheap and affordable to acquire. This paper reviews potential and pre-requisites of the seedball technology to improve the establishment of pearl millet seedlings under typical conditions (early seasonal drought and nutrient-deficient soil) of the West African Sahel.

II. THE SOCIO-ECONOMIC ENVIRONMENT

Sahelian farmers are mostly subsistence-oriented and frequently rely on a few cultivation plots. A landholding can be as small as four hectares per village, shared and cultivated by over fifteen farmers [18]. Scarcity of financial resource is the major factor hindering adoption of established mitigations strategies dealing with adverse effects of climate change [19].

The economic empowerment of women is globally recognised as a key factor towards reducing poverty and economic growth [20]. In most African farming systems, men retain the right to land, but can provide access to women through marital customs [16]. In few cases females can head households [21], controlling the overall agricultural activities in particular true for widows. On the contrary, regularly female spouses serve as aids [22], working under the instructions of their husbands. Innovations, addressing cropping systems in the African Sahel [9-11, 23] rarely focus on women empowerment. African female farmers in general, are less likely to adopt innovations for reasons such as complex and heterogeneous households, complicated and dynamic gender roles within households, and huge variation at responding to changes in economic circumstances [16]. Nevertheless, women provide more agricultural labour than men in the whole of sub-Saharan Africa [21]. Women first help their husband to crop his field before they are allowed to invest in their own plots.

In the African Sahel region, women account for > 50 % of the population. But they receive a disproportionately low share of public investment and are disadvantaged by a range of socio-cultural, regulatory and institutional factors. Even in the agricultural sector where women tend to predominate, credit and land ownership have historically been directed to the male head of the household despite of the fact that Sahelian women often outperform their male counterparts. In Burkina Faso, agriculture accounts for 36 % of the gross domestic product to which women contribute 29 % and men 7 %. In Mali these shares are 26 % to 14 % in favour of women [24]. These figures indicate the crucial role of women in agriculture that is often overlooked [25]. Women's farmland are often located at far distance from the homestead [26]. Land privatisations can cause the less privileged African women to completely lose their already acquired lands or reduce access to it [27]. These gender imbalances limit agricultural productivity as a result of underutilisation of human resources. Factors such as financial demand, indigenous resource input, labour requirement and education that restrict gender-specific adoption need to be evaluated before transferring any innovation to the field.

Seedballs need only local inputs such as sand, loam, seeds and water that are abundantly available at low costs. Little instruction is necessary to teach people how to produce seedballs. A major demand is labour. However, seedballs can be produced during the off-season when opportunity costs are low. Transport cost from the homestead to the field is higher for seedballs than for conventional seeds. Women usually crop only small plots, marginalising the transport costs. Taking these arguments together, the seedball technology may be particularly attractive in particular for women who own low fertility fields, farther away from the homestead that need to be sown at non-optimal times since men's fields are preferentially sown at the beginning of the cropping season.

III. THE NATURAL ENVIRONMENT

The West African Sahel (WAS) represents a transition zone between the arid Sahara in the north and the humid tropical savannahs in the south, noted for its steep north–south gradient in mean annual rainfall [28]. The cropping year is characterised by a long dry and a short humid season usually about three months. The northern Sahel that receives annual rainfall of 200 to 400 mm mainly represents grazing lands whereas the southern Sahel with an annual rainfall range of 400 to 600 mm serves as the pearl millet cropping domain. During recent times the WAS has seen a cyclic climate pattern at a decadal time scale. The deterministic reasons for the long-term fluctuations are not yet fully understood [8]. It is likely that non–El Nino-Southern Oscillation (ENSO) – related variations in sea surface temperatures [29, 30], and large-scale changes in land cover and land–atmosphere interactions [31-34], increasingly affect the Sahelian climate. The WAS has suffered from several devastating droughts and famines in the last decades, in particular in the early 1970s and the late1980s [35]. Farmers in WAS have to account for climatic variability at intra– and inter–annual as well as decadal time scales [36]. The possible consequences include species and variety losses. The variable and erratic rather than the overall low rainfall is considered as one of the most limiting factors for agricultural production [3, 4, 37] in this semi–arid environment. Seasonal weather forecasts have shown to be unreliable [38]. First, it is difficult for farmers to adapt to a variable seasonal length that is presently unpredictable. Therefore, farmers invest into risk diversification e.g. by adopting dry sowing [7] as a mitigation option. Secondly, early droughts pose a huge threat to seedlings survival directly after germination. It is of high interest to farmers to improve millet establishment and early vigour since the early growth stages are decisive for the final yield [9, 39]. The question of how to cope with these dry spells [40] is still a trending topic in the Sahel, particularly in the context of smallholder farming.

Therefore, reducing the risks of early seasonal drought and nutrient deficiency associated with dry sowing and infertile soil might be possible through seedball technology by amending seedballs with the suitable nutrient-additives to increase both nutritional status and drought tolerance in the seedlings. This might increase seedlings survival and vigour, reduce repeated sowing and subsequently increase the vegetative period of the crop.

IV. THE SOIL ASPECT

The major soils for Sahelian pearl millet productions are *Luvic Arenosols* [23, 41]. These soils are slightly acidic ($pH_{H2O} < 6$) and inherently deficient in plant available P [41, 42]. They are extremely low in organic carbon (< 1 %) and total N content [7] as well as available calcium (Ca) [43] but bear high potassium (P) reserves [44]. Additionally, they are coarse textured (> 70 % sand to 1 m depth), have a low water retention capacity (often < 10 vol. %), a high hydraulic conductivity [45], and are easy to till [46].

Different processes lead to surface crusting that negatively influences water infiltration at the start of the growing season [47]. Though rainfall is low, leaching losses of up to 200 lm^{-2} can accumulate over the season [48]. The so-called spatial micro–variability of soil properties (and corresponding yields) poses another challenge to the farmers [5], and are sometimes used as risk diversification strategy [49]. As population pressure forces an intensification of land use, integrated soil management is essential for cropping success. Such an approach combines improved soil moisture storage measures and the use of organic and inorganic fertilisers as well as other soil amendment options [50] to increase yield. Though atmospheric net nutrient input regularly occurs during the dry season, these are, with exceptions for P, too low to replenish the losses via cropping, leaching, wind and water erosion [44]. Extreme dryness, poor soil structure and lack of vegetative cover can increase the susceptibility of semi-arid soils, in particular *Arenosols* to wind and water erosion [51, 52], often leading to catastrophic crop losses.

Seedballs can - in the microenvironment - increase water retention due to their higher clay content and induce water transport towards the root by having a different water retention characteristic. The higher clay content can also contribute to a higher amount of rechargeable nutrient such as P, Ca and magnesium (Mg) directly around the seedlings roots.

V. THE CROPPING ASPECT

In small seeded species such as subterranean clover (*Trifolium subterraneum*), P and Ca seed reserves were exhausted as early as fourteen days [53]. In oats, most of the P reserves from the seeds were translocated to the developing roots and shoot during the first eight days after germination [54]. These results indicate that small-seeded species need nutrient supplementation as early as seedlings emergence. Pearl millet seeds are generally small and consequently bear a low nutrient stock. A single grain weighs 7 – 10 mg that contains P reserves of only about 20 µg. Therefore, additional nutrient input through pelleting appears promising [55]. In particular, an external supply of P soon after emergence is advisable [9]. Although pearl millets are naturally tough and can thrive in infertile soils [56], higher yields can be attained if seedlings are nutritionally enhanced as early as the emergence [23, 39]. An inevitable advantage of vigorous early growth arising from sufficient seed reserves is resistance against early stress conditions [57]. This is vital in the Sahelian region where plant establishment is often impaired by drought and sand wind blast occurring regularly, prior to the rainfall events [58].

Pearl millet and cowpea are the major Sahelian crops, since they are adapted to the harsh climatic and poor soil conditions. Due to the population pressure, fallowing is consecutively, abandoned and cropping is extended into marginal lands. Decreasing crop surface per household increasingly forces farmers to intercrop. A crop rotation as recommended by Bationo and Ntare [59] is hardly feasible anymore. Lack of fertiliser access on the markets as well as poor financial resources of households lead to nutrient mining [60] that is in long-term detrimental for the crop yield. One measure to counteract in particular nutrient deficiency during the early growth stages is micro-dosing [61]. This means small amount of fertiliser closely placed to the seeds in the sowing pocket. These small amounts of fertiliser do not include a high risk of no return on investment in case of crop failure. Traditionally, farmers wait with sowing activities until 0.10 - 0.15 m of the top soil are humidified by the starting rainfalls. Any delay in sowing then decreases yield potential [14] due to a shortened vegetation period and leaching of the already poor available nutrient fractions. Seedballs can potentially lower cropping risks by prolonging the growing period through dry sowing. When seeds are untreated, predation by rodents, pests and insects are often inevitable, causing the need for re-sowing. Seedballs ability to encapsulate seeds in hard form may reduce seed predation. A typical scenario herein is the observed 35 % reduction in seed predation of Tawa tree (*Beilschmiedia tawa*) when seeds were placed in balls made of nutritionally enriched clay in New Zealand [62].

Nutrient-enhancement effects of local materials such as wood ash [63], compost manure [64], charcoal [65] and termite mound materials [66] on soil and crops have been studied in the past. Wood ash has both long and short time effects on soils, and varies in its chemical contents depending on the burnt compounds, combustion process and ash conditioning [67]. Its application does not pose risks to the environment [68], but affects the soil chemistry in two ways; as a liming agent and as a source of nutrients [69]. Charcoals serve as soil conditioners and as sequesters of carbon in recalcitrant and in reactive forms [70], improving exchange capacity, surface area and nutrient contents [71].

Seedballs can potentially counteract the aforementioned cropping constraints by (i) reducing seed predation due to the - in the dry state - hard shell and providing small amounts of lacking nutrients that can improve seedlings establishment. Additionally, by directing water resources and again nutrients that might be otherwise leached from the surrounding towards the roots due to the higher water suction of the finer material. The only requirement is an optimisation using the specific local resources. Seedballs do not increase the nutrient status of soils. Therefore, the nutrients added need to be embedded in a holistic fertilisation strategy [72] that provides the necessary nutrients once the crop establishment is achieved.

VI. SEED TREATMENT TECHNOLOGIES

Different seed treatment techniques to improve pearl millet crop performance have been studied in the past. These include seed coating with P [9, 23], and seed coating and priming with *Pseudomonas spp*. under greenhouse and field conditions [73]. These techniques enhanced seedlings establishment and improved crop yield under field conditions. Karanam and Vadez [23] tested P coating using three-hybrid pearl millet varieties planted in pots (three seedlings per pot) or PVC cylinders (one seedling per cylinder), the latter option to allow for a longer growth span. The soil material used was derived from an *Alfisol* with low P status. In their findings, seed coating at a rate of approximately 400 g P ha^{-1} increased shoot biomass by > 400 % at early stage, and panicle weight by 50 % at harvest. The seed coating process of mixing pearl millet seeds with grounded KH_2PO_4 salt and glue solution at a specific-homogenised rate of 0.1 ml g^{-1} seed is already too sophisticated. Rebafka, Bationo and Marschner [9] tested the effect of enhanced seedling establishment achieved through P (ammonium dihydrogen phosphate) seed coating, on the final yield of pearl millet in an acid sandy, P deficient soil in Niger (West Africa). They observed a dry matter increment of up to 280 % in seedlings, and increased grain yield by up to 45 % in the field. However, the seed coating requires the use of highly sophisticated machine - a precision rotation pan - at a coating rate of not more than 0.5 mg P $seed^{-1}$ using bentonite as coating substance. Farmers may not replicate this coating practice due to its high skill demand. Again, the bentonite-containing phosphate salts used as the coating agent may not be available in the local markets, and might be practically impossible to be formulated by the farmers. Additionally, ensuring an accurate coating rate of exactly 0.5 mg P $seed^{-1}$ may be difficult, and this specified rate can impair germination when higher, or reduce yield when lower. In the findings of Raj, Shetty and Shetty [73], bio-priming pearl millet seeds with *Pseudomonas fluorescens* isolates resulted in an improved germination and seedling vigour, and subsequently led to up to 22 % increased grain yield in the field. However, the preparation (including centrifugation and pelleting), harvesting and storage of *Pseudomonas fluorescens* requires a King's B broth amended with 20 % glycerol and a cooling facility of -80 ^{0}C. Additionally, an ultra-violet-visible spectrophotometer was used to adjust the density to 10^8 cfu / ml before inoculation. Prior to inoculation, seeds were surface-sterilised with 0.02 % mercuric chloride, and further soaked in a bacterial suspension amended with 0.2 % carboxymethyl cellulose to facilitate the adherence of the bacteria to the seeds. This process is first, complicated due to high knowledge-demand with respect to the chemistry of the priming solutions, which the smallholder farmers lack. Second, the storage and cooling facilities require electricity and cooling devices. These are not within the spatial reach of the Sahelian subsistence farmers.

The decisive question for applicability is, whether farmers are able to apply a seed treatment technology, and this is depending on the level of mechanisation that is necessary. An innovation that needs high financial investments, components that are not locally available or includes technical aspects that are not manageable by local blacksmiths, will not find adoption in a subsistence-oriented agricultural environment. Therefore, a simple-to-understand and easy-to-apply alternative innovation is necessary; seedballs could be such a technology.

Seedballs as patently invented by Masanobu Fukuoka in which loamy soil was combined with compost manure, water and rice seeds, can be effective in converting bare land into forest [17]. As sowing technology, they can replace traditional seeds offering benefits of (i) enhanced early nutrient delivery (ii) reduced seed predation (iii) controlled seed amounts, and (iv) reduced labour input at sowing. If we theoretically apply this technology to the Sahelian environment, we can state the following. In contrast to other technologies, seedballs do not need enhanced technological equipment. The basic constituents (i.e. sand, loam, any kind of fertiliser e.g. compost, seeds, water) are in the hands of the farmers and accessible to both sexes. Producing seedballs needs little training. Production itself can be made by hand in a community action. However, if greater surfaces are to be planted, mechanisation is mandatory, since one hectare needs under Sahelian conditions and pearl millet as a crop approximately 10,000 seedballs (i.e. 1 seedball per planting pocket at a sowing distance of 1m*1m). Manufacturing can happen before the vegetation period if seedballs can be sufficiently dried immediately after production in order to impede unwanted germination. This is possible under the high daytime temperatures in the Sahel. Early production before the season allows for dry sowing. This is in particular an important aspect, since sowing at the start of the vegetation period is constrained by labour shortage.

The two crucial aspects for potential success of seedballs are that (i) seedballs show sufficient germination, and (ii) a growth advantage compared to conventional sowing. The pre-requisites for seedball production are (i) the availability of its components such as sand, loam, seeds, water, and organic or inorganic manure (ii) the dry and sunny atmospheric condition in the Sahel that ensures that seedballs dry in less than twenty-four hours after production, and (iii) human resources. These pre-requisites are, at low and affordable cost, within the reach of the every Sahelian farmer and his or her household. First of all, the seedballs need to be mechanically optimised in the sense that size, composition and number of seeds contained lead to a sufficient number of germinated seeds. The second step is then to add nutrient components. If these are mineral fertiliser or wood ash, the amount needs to be optimised in order to avoid osmotic effects that hamper germination or early plant development. Once seedballs are mechanically and chemically optimised, the next question is what kind of sowing technique is appropriate. In theory, seedballs can be applied directly onto the surface, as done in Australia for rangeland improvement [74]. However, it appears reasonable that incorporation into the soil is favouring water supply and thus better germination and growth. Timing of sowing is probably important, too. The technology was developed for application with dry sowing but also sowing at the onset of the rainy season might have advantages.

The last question is then, what the real mechanisms are, that contribute to the success of seedballs. Are these exclusively nutrient factors or are other effects involved? One could hypothesise that seedballs - as they have a finer texture than the surrounding soil matrix - are attracting water due to higher water suction. In combination with enhanced rooting density, this property can support survival in early seasonal drought periods, since more water is available to the plant, less energy is needed to extract this water from the surroundings and more nutrients are transported towards the plant that are otherwise potentially leached. In fact, certain plants can manipulate their rhizosphere under poor soil physiological status to increase nutrient availability [75], but to date, this is not proven for pearl millet. Therefore, seedballs might be a management option that can act as a substitute for this disability, particularly in the chemically infertile Sahelian *Arenosols*.

Another advantage of seedballs is that the incorporated seeds are hardly accessible to predators such as birds, small mammals or ants until the suitable germination conditions are met [76]. A known number of seeds can be inserted into seedballs. It is important to identify this number in a participatory manner with farmers, since the number of existing plants per pocket does not only play a role as yield component but also to counteract harmful erosion events. Under Sahelian conditions, at the onset of the rainy season, strong convective storm events regularly occur [77]. The saltating sand grains during these events can impact on pearl millet seedlings to such an extent that they die. Therefore in one sowing pocket more seedlings need to be established than is necessary only for the yield aspect. In a sowing pocket the outer plants protect the inner ones against erosion effects.

With conventional manual sowing under Sahelian conditions, an unknown seed amount is incalculably inserted into the soil. Seed wastage is most prominent when children do the sowing. They tend to increase the seed amount per pocket when they become tired. And this effect can be massive. Klaij and Hoogmoed [46] reported an insertion of up to 300 seeds per pocket as conventional practice. Consequently, irrespective of who does the sowing with seedballs, sowing can become more economical from the perspectives of required seed amount and labour. With respect to the latter seedballs can reduce the demand for thinning activities and in case of efficient emergence for replanting. All these benefits would support, in particular, women farmers who have the lowest resource availability.

VII. CONSTRAINTS TO ADOPTION

Only a few research findings on enhanced pearl millet production technologies have passed on to the Sahelian farmers during the last decades. This is partly caused by lacking skills and financial resources of farmers but also by lacking extension services and the top-down attitude in the researcher-extensionist-farmer continuum. Buerkert and Schlecht [61] stated that there are three pre-requisites for success of agricultural innovations in Sudano-Sahelian West Africa. These are (i) enhanced farmers' access to markets (ii) low cost innovations, and (iii) limited risk of no return on investment. Herrmann, Haussmann, van Mourik, Traore, Oumarou, Traore, Ouedraogo and Naab [78] called for a paradigm change in research, pledging for more participation of and giving more responsibility to farmers. They state that the empowerment of farmers leads to faster progress with respect to innovation testing, adaptation and sustainable adoption. For local farmers, adapting and adopting innovations is a complex process that involves risk considerations. Technologies are easier adopted if they relate to the knowledge background of the farmers and when they can be observed and evaluated (e.g. in demonstration plots) before they enter into on-farm testing. Cropping risks related to a technology and its handling need to be made explicit. Adaptation – that means change of a technology according to the needs and capacities of a farmer needs to be accepted by the researchers, and become a regular concept in their activities. Several workshops held with the Sahelian smallholder pearl millet farmers revealed that the application of seedballs has no disadvantages in the Sahel region [79]. In fact, it was reported (i) that the indigenous local material components of seedballs are freely available (ii) that all gender can easily produce seedballs, and (iii) that seedballs application might be economical due to low financial demand and rational use of seeds. Neither religious beliefs nor other habits hinder potential adoption of seedballs.

VIII. CONCLUSIONS, OPEN QUESTIONS AND RESEARCH DEMANDS

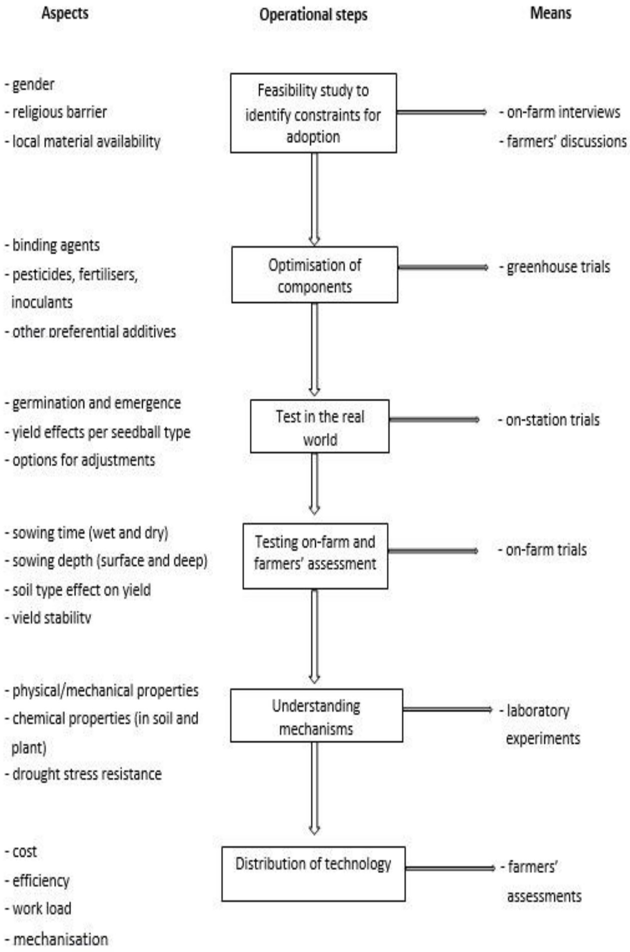

Fig. 1. Proposed operational scheme for the development of the seedball technology in the Sahelian smallholder farming

Reviewing what was discussed above, it appears possible that the seedball technology has advantages under Sahelian conditions since it is a cheap technology based on locally available resources that does not disadvantage any sex. However, it is also clear that this technology needs to be adapted and optimised. A panicle yield increment of about 30 % in pearl millet was observed in several on-farm trials in 2016 planting season in Maradi region, Niger Republic. In fact, seedball technology is interesting for other semi-arid areas such as Rajasthan in India, Punjab and Singh in Pakistan. However, it is of scientific interest to know which mechanisms contribute to the success of the technology in order to refine recommendations and to develop the technology further.

In order to make it operational, the following scheme appears reasonable. First of all, farmers in different regions need to be interviewed with respect to potential constraints for adoption. If no major barriers are revealed, the mechanical and chemical optimisation can start. This is best to be done in greenhouse trials, considering aspects like optimal binding agent, nutrients and pesticides as additives. For the latter, care must be taken that local farmers might be able to apply those chemical compounds in a reasonable and comprehensive manner. Once greenhouse trials show the defined performance (e.g. with respect to germination rates or biomass indicators) first trials can be performed under field conditions in the Sahel. Optimally, one starts with researcher controlled trials in order to avoid too many uncertainties with respect to interpretation of trial results (e.g. non-communicated additional farmer treatments). If these on-station trials are performing, the test phase with demonstration plots in different villages can start. These can yield additional information on necessary adaptation to local conditions and in particular gender preference and labour demand. Finally, farmers are free to experiment with the technology only reporting which additional management measures have been taken. Again, this information can help to improve the performance of the technology and to develop a final technical sheet for extension purposes.

With respect to the Sahelian conditions in particular, Schlecht, Buerkert, Tielkes and Bationo [80] and Fowler and Rockstrom [81] reclaimed (i) to develop a simple–to–understand technique (ii) which can increase resource use efficiency (iii) and that is compatible with the socio–economic level of the target rural farmers. Therefore, the seedball technology should use freely available, and inexpensive local materials such as sand, loam, termite mound material, charcoal, animal dung or wood ash. With respect to mineral fertiliser as nutrient additive in the seedballs, only minute amounts per hectare (i.e. several kg) are required; these are available and affordable to smallholder West African Sahelian farmers in particular.

Finally, research on socio–economic advantages in the target Sahelian region is mandatory before this technology can be massively distributed to the farmers. Additionally, a proper assessment of gender equality, adoption scenarios, and mechanisation for mass production at low labour cost appear meaningful.

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