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Agricultural management and environmental requirements for production of true shallot seeds – a review

Abstract

Shallots widely grow in very cold to moderate cold temperate climates at high elevations. Due to low seed production rate and the lack of seed producing cultivars, in most cases, shallots are vegetatively propagated by using bulb material. Cultivation of high-quality true shallot seeds (TSS) under suitable environmental conditions and agricultural management have several advantages over bulb materials, such as, smaller quantity of planting materials, easier transportation, long-term storing capacity, production of large and disease-free bulbs, and greater yield. Most studies focus on improving shallot bulb production and understanding the agricultural methods for improving yield and quality of TSS require more attention in the future. Hence, this review discusses the most efficient methods for production of TSS.

Keywords: *Allium*, Mooseer, medicinal, bolting, dormancy, sexual reproduction, shallot seed, seed reproduction, true shallot seed, vernalization

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Introduction

Shallot is an economically important nutritive vegetable and medicinal plant belongs to *Allium* as the sole genus with over 900 species in the Allieae tribe, one of four tribes of subfamily Allioiideae subfamily of monocotyledonous flowering plants in the family Amaryllidaceae, order Asparagales. Allioiideae was formerly known as Alliaceae in a separate family.[1–5] Shallots are originated from Western Asia and worldwide with a weak geographically distribution are cultivated and in most cases widely grow in limited regions of few countries, largely in Asian countries. Shallots require specific edaphoclimatic conditions, i.e., in very cold to moderate cold regions at high elevations usually more than 1000 m above sea level, and precise agricultural management to overcome bulb and seed dormancy, and induce seed stalk development and reproduce bulbs and true seeds.[6–11] Planted under suitable environmental condition and agricultural management, high- quality true shallot seeds (TSS) have a high potential as an alternative planting material. The advantages of using TSS include, unbulky and less expensive planting materials, easier transportation, long-term storage capacity, production of healthy bulbs free of pathogens and larger bulbs, a shorter period between planting to harvesting time (depending on plant species and genotypes and environmental conditions in field or greenhouse the growth cycles can be shorter or longer), and higher yield.[12–15] The most common fungal diseases infecting vegetatively (asexual) propagated shallot bulbs are *Fusarium* sp., *Colletotrichum*sp, and *Alternaria* sp.[13] The common virus diseases include *Shallot latent virus* (SLV), member of genus *Carlavirus*, *Onion yellow dwarf virus* (OYDV), *Shallot yellow stripe virus* (SYSV), and *Leek yellow stripe virus* (LYSV), members of genus *Potyvirus*, and shallot *mite-borne filamentous virus* (ShMbFV; syn. *Shallot virus X,* ShVX), member of genus *Allexivirus*.[16–20] However, the lack of information on the breeding and selection of shallot populations capable of producing high true seed yield and quality traits, and high viability are the main reasons of using bulbs as the planting materials.[14] Besides the unavailability of high-quality seeds adapted to specific environmental conditions, high prices of planting materials of any kind at planting date, long distance transportation, and lack of knowledge of breeding shallots for TSS production, as well as low percentage of bolting and seed production rate are the main reasons that persuade farmers to store seed bulbs for 3 to 5 months as the planting materials. Long-term bulb storage increases the incidence of various diseases, including viruses, fungi, and bacterial pathogens as well as nematodes and reduces farmers' revenues.[11,21] In this regard, to overcome these problems this review article aimed to evaluate the current information for producing high-quality TSS.

Environmental conditions and agricultural management for production of TSS

The influence of environmental factors on bulb and true seed production greatly vary among shallot species and populations. Suitable environmental conditions and agricultural management are required to overcome seed and bulb dormancy, induce bulb sprouting, seed germination, flower stalk development (bolting), flowering, and finally to produce seeds and bulbs with high yield and quality.[7–14,22] Since the information on TSS production methods is still evolving, preliminarily experiments are required to evaluate the effects of interacting internal and external factors on yield and quality of TSS via seed-to-bulb-to-seed and bulb-to-seed production methods.

Approximately, 1.5-5 kg ha^{-1} seeds[14,21] or 1.2-2 t ha^{-1} bulbs at 15× 20 cm plant spacing and 20 bulbs m^{-2} are required as the planting materials for shallot bulb production.[22–26] For TSS production, differential responses of shallot populations and environmental factors should be taken into consideration for managing agricultural practices such as planting date, plant spacing and density and fertilization. For example, 175 plant m^{-2} and 180 kg N ha^{-1} and 75-100 plant m^{-2} and 240 kg N ha^{-1} were the most effective treatments for producing TSS of 'Tuk-tuk' and 'Sanren' cultivars, respectively.[15] Hence, for TSS production, 'Tuk-tuk' and 'Sanren', respectively, require about 3.75 to 8.75 times more planting materials compared to the cultivation method for bulb production. Future studies are required to assess the optimum planting material for TSS production of different cultivars under specific agricultural management and environmental conditions.

Sumbayak and Susila's[27] study showed that the integrated two-line spray hose irrigation (50 mm tube width [flattened] on the surface of mulch set to 130-420 mm min^{-1} m^{-1} water feed rate to cover 200 cm width of irrigated bed) with polyethylene (Sumisansui-MARK II; which is black) mulching (at 15×20 cm plant spacing in 1 m width×22 m length×0.5 m height bed dimensions and 50 cm distance between beds) had a greater efficiency than conventional Surjan system to enhance the productivity of shallot (bulb yield and quality). More efficient than black film, transparent polyethylene film has been used to increase (21%) shallot (A. cepa var. ascalonicum Backer) productivity.[10] Preparation of the planting materials including true seed germination of true seeds, and bulb sprouting, vernalization and cultivation methods based on seed-to-bulb-to-seed and bulb-to-seed production methods are discussed in the following sections. Future studies can evaluate the best fertilization practices by deploying joint application of organic-inorganic fertilizers, biofertilizers, and spraying micronutrients. In this context, the present review evaluates the most effective treatments to enhance shallot productivity in the future. Depending on genetic characteristics and environmental conditions, the most effective inorganic fertilization in both bulb and true seed production methods have been reported in the ranges of approximately 169 kg ha^{-1} N, 50-160 kg ha^{-1} P_2O_5, 50-200 kg K_2O and irrigation with 2025 m^3 water ha^{-1}.[4,15,28–30] Nitrogen use efficiency can further be improved by using the combination of 100 kg ha^{-1} N and 1000 L ha^{-1} Biourine.[31] Organic fertilization by 60 t ha^{-1} cow manure has been more effective for increasing TSS, whereas 40 t ha^{-1} cow manure was more efficient for increasing bulb dry yield.[23] The positive impact of 10 mg L^{-1} pre-treatment (soaking bulbs for 24 h) and 100 mg L^{-1} foliar spraying 1-(2-Chloro-4-pyridyl)-3-phenylurea known as forchlorfenuron (CPPU) on improving bulb dry yield, phenols, antioxidant activity, and protein content has been documented.[7] The efficacy of CPPU application on TSS production remains to be investigated. Reducing the need for NPK by 50%, application of 20 t ha^{-1} chicken manure was more effective than cow manure, paitan (Tithonia diversifolia), Crotalaria juncea, urea, SP36 (superphosphate, 36% P2O5), and KCl in increasing shallot A. ascalonicum L. bulb yield.[32] Considering the higher the need for cow manure for TSS production,[4] future studies are required to examine if 30 t ha^{-1} chicken manure would be more efficient for TSS production. Future studies are also required to increase the knowledge of using the integrated agricultural management including fertilization (combination of biofertilizers, organic, and inorganic fertilizers), polinization, irrigation and mulching practices on TSS production. Before planting shallots, Tagetes planting should be carried out around the field to attract pollinators, and 5 boxes honey bee) *Apis cerana* (nests per 1000 m^2 should be installed when flowering begins.[33] Honey bee (*Apis cerana*), forest bee (*Apis dorsata*), butterfly, and green fly (*Phaenicia sericata*) are good pollinator species for onion and shallot.[33] The difference in the requirements of agricultural management practices are represented in details for bulb-to-seed and seed-to-bulb-to-seed production methods.

Bulb to seed production methods

Shallots are mainly reproduced in vegetative way since they rarely produce generative shoots or seeds. In addition, the knowledge of breeding cultivars capable of producing commercial seeds is scarce.[34] In this regard, understanding the environmental requirements and agricultural management is an essential step for producing TSS. Bulb-to-seed phonological stags take about 8 months, depending on genetic characteristics, adaptation to the cultivated region, and environmental conditions. For example, bulb-to-seed production method for Persian shallots *A. hirtifolium* Boiss. Lorestan landrace and local landrace *A. altissimum* Regel Kalat in Khorasan Province in north-eastern Iran respectively takes 237 to 252 days from mid fall, before lowering the temperature to freezing point, till the end of spring.[10,35] Vernalization by overwintering or by storing bulbs or seedlings at 4-6 ˚C for about two months (usually 4 to 8 weeks depending on genetic characteristics) induces bulb sprouting (in the case of using bulb material) and increases bolting percentage and thus seed production.[7,22,33] Vernalization and flowering are under the influence of interacting internal and external factors. GA_3 encourages vernalization, bolting, flowering (flowering precocity, intensity, and fertility), and seed production. However, its efficacy varies depending on its dosage(s) at specific growth stages, plant genetic, elevations, photoperiod, and temperature.[7,14,22,30,36–39] Shallot bulb sprouting occurs when temperature rises to 3.3 to 5.9, and plants grow well at 13 to 24 ˚C. At high elevations, flowering naturally occurs at 9-12 ˚C and long photoperiod. However, low elevations and high temperatures above 26 ˚C prevent flower stalk development and flowering. In such conditions, vernalization or hormone application (for example, by soaking bulbs and spraying plants with hormones such as GA_3), can be used to induce flowering.[7,10,14,22,40] The influence of vernalization varies depending on plant genetic, planting materials, duration of low temperatures at specific growth stages, photoperiod, and elevations.[26,40] Taking the influence of genetic characteristics into consideration, selection of appropriate cultivars under suitable environmental conditions (cold climate, highland, long photoperiod) and agricultural management (such as planting date, fertilization, and hormone application) can promote yield and quality of shallots seeds and bulbs. A comparison between *A. cepa* L. var. *ascalonicum* Backer 'Toto', 'Ambition F1', 'Bonilla F1', and 'Matador F1' cultivars and one local population ('U') showed that, correlated with bulb diameters, 4-6˚C, 8-10˚C, and 0-1˚C were respectively the most effective bulb storage temperatures to induce bolting (respectively 36.5%, 30.5%, and 25.3% on average) and seed production. Bolting percentage of mother bulbs with larger bulb diameter was 3.6 times more than the mother bulbs with small bulb diameter. In the same way, 4-6˚C had the greatest positive impact on seed weight and yield, particularly on large bulbs with 41-50 mm and 51-60 mm diameters. Seed production was almost inhibited by using 0-1˚C storage temperature and local population 'U'. Considering the seed production of 'Tota', the highest seed weight (0.89 g seed per umbel) and seed yield (2300.7g $100m^{-2}$) were both obtained by storing large mother bulbs with 51-60 mm diameter at 4-6˚C.[11]

Seed to seed production methods

Seed-to-seed production methods require agricultural management and breeding strategies to improve bolting, flowering, seed yield and quality (such as weight and size with strong vigor), seed germination, seedling growth, and at the same time to obtain high-quality bulbs with marketable yield.[35,41] Apart from non-dormant seeds like *Improved Huruta* variety, most shallot true seeds require approximately 21 to 60 days for breaking seed dormancy and 25 days for seedling growth in nursery before transplanting to the main field. Seed-to-bulb-to-seed (or seed-to-seed) production takes about 10-11 months.[7,13,35,41] Priming and pre-sowing have been effective in improving true shallot seed germination parameters.[1] Depending on the types of seed dormancy mechanisms, which differ among shallot populations, different treatments are required to break the dormancy.[41] Single or joint application of hormonal (such as GA_3) and chemical [such as potassium nitrate (KNO_3)] treatments as well as scarification and cold stratification have been effective in breaking seed dormancy of shallots.[12,41] According to Ebrahimi et al.'s[41] experiment, harvested mature seeds were kept at room temperature for two months to reduce their moisture down to 8-10% and then the combination of sandpaper scarification for 3 min followed by 45-day moist-chilling at 4°C began by soaking into 500 mg L^{-1} GA_3 for 12 h was used as the most effective treatment with 100% seed germination for breaking seed dormancy of *A. hirtifolium* Boiss. 'Sanandaj' accession. Sandpaper scarification alone without stratification led to 83% seed germination and normal seedling growth. They showed that in the presence of scarification either by soaking into 95% sulfuric acid for 15 min or by scratching on sandpaper for 3 min and stratification at 4 °C for 45 days, 100% seed germination and proper seedling growth occur without applying GA_3 or KNO_3. However, it remains to be verified if GA_3 can promote seed germination and seedling growth when seeds are planted in the field condition in cold regions where seeds dormancy naturally breaks by nature. In another experiment, GA_3 (100, 150 and 200 mg L^{-1}) and KNO_3 (1 M) have been effective in improving seed germination (speed and percentage) of *A. cepa* var. *aggregatum*.[12] As a mechanical constraint mechanism, seed coat dormancy can be caused by covering layers including pericarp, testa, and endosperm. It can be inferred that scarification of *A. hirtifolium* Boiss. 'Sanandaj' true seeds removed pericarp and testa and awakened endosperm by reducing its mechanical resistance to respond to external factors, such as, moisture, low temperature, oxygen, and GA_3.[41] GA_3 could then promote biochemical reactions such as reducing the inhibitory effects of ABA by changing GA_3/ABA ratio and also inducing the synthesis of hydrolases, particularly α amylase in seeds endosperms.[12,41] Consequently, the synthesized α amylase provides energy for seed germination by increasing permeability of membranes and, thereby, increasing the activity of enzymes involved in protein synthesis and carbohydrate metabolism.[1] Priming 'Tuk-tuk' TSS by soaking into 25 ml solution of 100 ppm GA_3 for 24 h markedly improved seed germination percentage, seed germination speed, seedling vigor index, speed of seedling emergence, percentage of seedling having at least one first true leaf and had superior effect than KNO_3 importantly in terms of seed germination speed.[12]

Allium cepa var. *ascalonicum* Backer *Improved Huruta* shallot variety has been bred to enhance TSS production and was approved for cultivation at mid and high altitude areas of eastern Ethiopia and similar agroecologies of the country. *Improved Huruta* produces marketable bulb with the mean weight of 72 g, 36.4 and 45.14 t ha^{-1} marketable and total bulb yields, and with 95% average bolting produces 5.72 g per plant and 953.6 kg ha^{-1} seed yield. *Improved Huruta* seeds have no dormancy and can be stored for two years with 98% average germination capacity four days after sowing.[35] Depending on shallot accessions (i.e., cultivar or variety), planting dates significantly affect seed stalk development and seed yield. A comparison among *A. cepa* var. *ascalonicum* Backer cultivars viz. 'Toto', 'Ambition F1', 'Bonilla F1', and 'Matador F`1' showed that 2- to 4-week delay in seedling planting date (4-week greenhouse grown seedlings at 2-3 leaf stage and about 12 cm height) after the 3rd decade of July (early summer in Lublin, Poland) severely reduced the percentage of bolting, flowering, and seed yield, which was intensified in 'Toto' cultivar. 'Matador F`1' and 'Toto' cultivars respectively had the highest and lowest bolting percentages.[11] In addition to improving seed yield, the bred cultivars should also have a high potential to produce marketable high-quality bulbs. Planting material can affect bulb characteristics such as weight, size, numbers, and yield. For example, *A. cepa* L. Aggregatum Group shallots produce clusters with a large number of daughter bulbs by planting bulb materials, whereas their sexual reproduction leads to the formation of approximately 1 to 3 daughter bulbs.[11]

Methods to improve flowering and seed yield and quality

In addition to cultivation methods such as planting date, spraying plant growth regulators, nutrients, etc. can control flowering and seed production.[11,33,42] Knowing the fact that increased cytokinin:auxin ratio induces shoot development and flowering, Prahardini and Sudaryono[33] immersed seedlings roots into 37.5 ppm 6-benzylaminopurine (BAP) for an hour and then treated them with Dithane M-45 Fungicide before planting. Low temperature is more critical at low elevations to induce bolting. GA_3 cannot replace cold temperature and long photoperiod (above 12 h) particularly in lowlands.[38,39] In lowlands, a combination of applying GA_3 and vernalization promotes flowering and TSS production.[36] Planting shallots in at least 12 h and optimum 16 h photoperiod and application of approximately 200 ppm GA_3 at different phenological stages, i.e., by soaking bulbs for 30 min, foliar spraying at 2-3 and 6-7 leaf stages, and at the time of flowering, were effective in promoting yield and quality of TSS.[14,38,40] Like GA_3, naphthaleneacetic acid (NAA) was effective in improving both yield and quality of true seeds in onion and shallot.[36,43] Single spraying of 100 ppm NAA and 100 ppm GA_3 at flower stalk emergence and 10 percent flowering improved seed yield and quality of onion (*A. cepa* var. *aggregatum*).[43] Similarly, foliar spraying of 50 ppm NAA at different growth stages was effective in improving shallot flowering and true seed production.[36] Cycocel (CCC) (chlormequat; 2-chloroethyl trimethyl ammonium chloride) is a growth retardant compound that inhibits gibberellin biosynthesis and stimulates cytokinin synthesis. Application of 1000 ppm CCC inhibited flower bending in onion (*A. cepa* L. 'Giza 20'), as the result of reducing stalk height and increasing its thickness, and also improved seed yield and quality.[37] To our knowledge, CCC might induce similar effects on shallots, which has not been studied so far. Foliar spraying of mineral nutrients, importantly boron (B), zinc (Zn), calcium (Ca), and magnesium (Mg), particularly during the active growth stages has been effective in improving yield and quality of different plants/crops. Nutrients deficiency mostly afflicts high yielding plants grown in poor soils having low organic manure, imbalance NPK fertilizers, poor quality water and water deficiency, and soil erosion. Foliar application of mineral nutrients has been more efficient than their soil application since their adsorption and efficiency are not negatively affected by poor quality soils, antagonistic effects of nutrients, and water deficiency. Spraying of these mineral nutrients in the form of borax (625 g h^{-1}), zinc-ethylene diamine tetra-acetic acid (Zn-EDTA; 500 g h^{-1}), Ca-EDTA (500 g h^{-1}), and Mg-EDTA (500 g h^{-1}) at active vegetative and reproductive stages, i.e., 30 and 60 days after planting (DAP), promoted yield and quality of both bulb and true seed in onion (*A. cepa* L. 'Pusa Riddhi').[42] Prahardini and Sudaryono,[33] sprayed shallots with 3 kg ha^{-1} B in the forms of borax and boric acid at 3 different growth stages during production of TSS, but how its effectiveness varies depending on its concentrations and combined application with other stimulators remains to be studied. Foliar spraying of micronutrients, Borax, and KNO_3 were respectively the most effective treatments for improving seed yield and quality of *A. cepa* L. 'Arka kalyana'.[44] In onion (*A. cepa* L.), combined application of 75% of recommended dose of NP fertilizers and 2.5 t ha^{-1} vermicompost had greatest effectiveness on improving both seed yield and quality (seed germination percentage, germination speed, and seed vigor) compared to a single treatment.[45] However, different fertilization practices are required for bulb production so that the highest yield values of onion were obtained by integrated nutrient management of 50% N plus 5 t ha^{-1} vermicompost.[46] The efficiency of combined application of organic and inorganic fertilizers and biofertilizers has been less studied for TSS production than for bulb production. Joint application of nutrients under precise agricultural management such as cultivation practices (such as planting date, as well as plant spacing and intensity) and fertilization methods (such as combination, dosages, and timing) may further improve shallot productivity in the future. Yet, understanding the influence of joint application of hormones, nutrients, and biofertilizers with different dosages at different growth stages and their interactions with agricultural management, genetic characteristics, and environmental conditions on yield and quality of shallot bulb and true seed require extensive examinations.

Concluding remarks

Plant genetic and environmental conditions should be considered to determine the most efficient agricultural management for production of TSS. For bulb production, 169 kg ha^{-1} N (or 100 kg ha^{-1} N and 1000 L ha^{-1} Biourine), 50-160 kg ha^{-1} P_2O_5, 50-200 kg K_2O and irrigation with 2025 m^3 water ha^{-1} or its half dosage combined with organic manures such as 20 t ha^{-1} chicken manure or 40 t ha^{-1} cow manure increase shallot bulb yield and quality. For TSS production higher organic fertilizers (for example, 60 t ha^{-1} cow manure) are required. Planting cultivars with high potential for producing true seeds under suitable environmental conditions at the right time is a critical step. Since plant intensity is higher for production of TSS compared to bulb production, future studies are yet required to assess the best fertilization practices for production of TSS. Future studies are required to provide more information regarding the integrated fertilization practices consisted of organic and inorganic fertilizers, biofertilizers, and spraying macro and micronutrients and combined hormone application under the appropriate cultivation practices, mulching, and irrigation methods such as two-line spray hose irrigation.

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Conflicts of interest

The authors declare there is no conflict of interest.

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