ONTOGENETIC STAGES OF PLANTAGO OVATA FORSSK

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Abstract. This thesis examines the individual development, or ontogeny, of Plantago ovata Forssk. (ispaghula, psyllium) as a continuous process extending from seed dormancy through germination, formation of vegetative organs, transition to the generative phase, differentiation of the spike-like inflorescence and floral organs, post-anthesis capsule and seed development, and final senescence. The Kew Plants of the World Online database recognizes P. ovata as an accepted species of the family Plantaginaceae and indicates a native range extending from southeastern Spain and North Africa toward India and Somalia, as well as parts of arid North America. Modern developmental studies report that the life cycle from germination to full maturity may last approximately 3.5 months. Reproductive ontogeny includes floral budding, initiation and complete formation of floral organs, full flowering, and fruit maturation. A 2025 morpho-developmental study further divided post-anthesis capsule development into fruit set (1–7 days post anthesis, DPA), expansion (8–17 DPA), ripening (18–23 DPA), and maturity (after 23 DPA). Precise characterization of these stages is important for seed production, phenological monitoring, determination of harvesting time, and management of medicinal raw-material quality.

Keywords: Plantago ovata, ispaghula, psyllium, ontogeny, germination, juvenile stage, vegetative development, reproductive development, inflorescence, capsule, seed, phenology.

INTRODUCTION

Plantago ovata Forssk. belongs to the family Plantaginaceae and is an important raw material for the pharmaceutical and food industries because of its seeds and, particularly, the mucilaginous polysaccharides present in the seed coat. Ontogeny is especially important for understanding the biological characteristics of the species because its economic value is directly associated with reproductive development, capsule formation, and morpho-anatomical maturation of the seed.

Ontogeny is the individual development of an organism from the zygotic or seed stage to the natural completion of its life cycle. In plants, this process is expressed through a sequential series of morphological, anatomical, and physiological changes. In P. ovata, the principal reference points for ontogenetic analysis include seed imbibition and germination, formation of true leaves, accumulation of vegetative biomass, differentiation of inflorescence primordia, flowering, fruit and seed development, and senescence.

The phenology of the species is environmentally dependent. Kew data indicate that flowering and fruiting in parts of the natural range may occur from February to June, whereas the timing shifts in other regions according to climate and sowing date. Therefore, describing ontogenetic stages by morphological markers and developmental events is scientifically more reliable than using fixed calendar dates.

MAIN PART

Latent and Germination Stages

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The ontogeny of P. ovata begins with a morphologically mature seed. When the seed absorbs water, the mucilage-producing cells of the seed coat hydrate rapidly. Classical and modern studies of seed-coat development show that accumulation of mucilage in epidermal cells is a characteristic structural feature of the seed. Upon contact with water, this layer forms a hydrogel that can influence the moisture regime of the seed microenvironment.

Germination begins with water imbibition, activation of metabolism, and emergence of the radicle through the seed coat. Germination of P. ovata seeds is sensitive to temperature. Experiments by McNeil and Duran showed that germination of fresh seed decreased as incubation temperature increased, while a short low-temperature pretreatment at approximately 15°C could shorten both the time to germination and the period to 50% flowering by as much as three weeks. Thus, the earliest stage of ontogeny can substantially influence the subsequent phenological rhythm.

During the seedling stage, the radicle elongates and the primary root system develops; cotyledons and subsequently true leaves assume the major photosynthetic function. At this stage, seedlings are particularly sensitive to environmental factors, and water deficit, high temperature, or surface soil crusting may strongly affect plant establishment.

Juvenile and Vegetative Development

With the successive formation of true leaves, the plant enters the juvenile stage. Its principal characteristics are rapid expansion of the photosynthetic surface, deepening of the root system, and formation of a rosette-like vegetative structure. P. ovata is generally a low-growing plant that branches from the base and, at maturity, produces narrow elongated leaves and numerous spike-like inflorescences.

The vegetative stage can be quantified through leaf number, leaf length and width, rosette diameter, root length, and dry biomass. In general plant-development ontologies, vegetative development includes germination, main shoot or leaf development, and formation of lateral shoots. In a phenological observation system adapted to P. ovata, the sequential unfolding of leaves after germination can likewise serve as a principal marker until the transition to reproductive development.

The duration of the vegetative phase is determined by genotype and environment. Experiments involving temperature and seed pretreatments demonstrate that both the length of the vegetative period and the onset of flowering can change. Consequently, the number of days recorded in one region should not be used as an absolute ontogenetic criterion for another region.

Reproductive Induction and Inflorescence Formation

A major turning point in P. ovata ontogeny is the transition from the vegetative to the reproductive state. Histological work by Sarma and Vora showed that the inflorescence initial does not arise directly from the shoot apical meristem or the axils of the youngest leaves, but appears in the axils of relatively older leaves. The primordium subsequently develops into a spike primordium. This feature is important for correct morphological interpretation of reproductive organogenesis in the species.

A detailed study of reproductive development distinguished five stages: Stage I — floral budding (day 0); Stage II — floral-organ initiation (day 4); Stage III — floral-organ formation (day 8); Stage IV — full flowering (days 12–16); and Stage V — fruit maturity (day 20). Flowers in the spike are numerous, small and white, and consist of sepals, petals, four stamens, and a pistil.

The inflorescence shows acropetal development: flowers in the lower portion of the spike develop earlier than those toward the apex. Consequently, flowers and later capsules at different developmental states may occur simultaneously within a single spike. This asynchrony results in non-uniform seed maturation and should be considered when determining the optimal harvest time.

Flowering, Fertilization, and Fruit Development

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At full flowering, the stamens become functional, and after pollination and fertilization the ovary develops into a capsule. The mature fruit of P. ovata is a circumscissile capsule, or pyxidium, which opens along a transverse line. Its upper part separates as a lid, or operculum, whereas the lower part remains attached to the spike axis.

A morpho-developmental study published in Annals of Botany in 2025 provided a more precise division of post-anthesis capsule ontogeny: 1–7 DPA (days post anthesis) — fruit set; 8–17 DPA — capsule expansion; 18–23 DPA — ripening; and after 23 DPA — full maturity. During the first week, capsule size was observed to increase approximately threefold. Within the seed, integument layers predominate initially and are progressively compressed by the developing endosperm, embryonic cotyledons, and radicle.

An earlier metabolomic study followed the overall reproductive sequence from floral budding to fruit maturity over approximately 20 days, whereas the 2025 study monitored post-anthesis capsule maturation to 23 days and beyond. These values are not necessarily contradictory because the studies used different starting points and stage definitions. For ontogenetic research, it is therefore advisable to record both days after sowing and days post anthesis (DPA).

Morpho-anatomical Maturation of the Seed and Formation of the Mucilage Layer

Because the economic and pharmacognostic value of P. ovata is largely associated with the mucilage in the seed coat, seed ontogeny deserves special attention. Mucilage-secreting epidermal cells of the seed coat undergo marked differentiation during development. Early anatomical studies reported that these cells may increase in volume by approximately 60–80 times during seed maturation and become almost completely filled with mucilaginous material.

A modern study in Scientific Reports described in detail the accumulation, storage, and water-triggered release of mucilage from the seed coat. This property is important both for biological adaptation of the seed and for the technological quality of psyllium products. Consequently, ontogenetic field studies may assess not only seed dry mass, but also thousand-seed weight, germination capacity, seed-coat proportion, and mucilage-forming capacity as indicators of maturation.

When the capsule reaches full maturity, the dehiscence zone becomes functional and separation of the operculum permits seed dispersal. Delayed harvesting may increase the risk of natural seed loss, whereas harvesting too early may prevent complete physiological and technological maturation. Changes in capsule colour, seed moisture, and dehiscence status should therefore be monitored together when defining harvest maturity.

Senescence and Completion of Ontogeny

After seeds reach physiological maturity, senescence intensifies in the vegetative organs. Photosynthetic activity of the leaves declines, green colour is lost, tissues dry, and the transfer of assimilates to reproductive organs is completed. In P. ovata grown as an annual crop, this process marks the completion of the life cycle.

Table 1. Main Ontogenetic Stages of Plantago ovata and Their Diagnostic Characteristics

Ontogenetic stage	Main morphological feature	Recommended observation	Biological significance
Latent/seed	Mature dry seed; mucilaginous seed coat	Seed weight, moisture, germination capacity	Initial state of the next generation
Germination	Imbibition, radicle emergence, seedling	Germination %, germination energy,	Establishment of the plant population

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	appearance	number of days	
Juvenile	Sequential appearance of true leaves	Leaf number, rosette diameter, root growth	Independent photosynthetic development
Vegetative	Active growth of leaf biomass and root system	Biomass, leaf area, growth rate	Resource accumulation before reproduction
Reproductive induction	Inflorescence primordium in axils of older leaves	Appearance of primordium and spike	Vegetative-to-reproductive transition
Flowering	White flowers opening acropetally along the spike	Beginning, 50%, and end of flowering	Pollination and fertilization
Fruit set/expansion	Capsule growth at 1–17 DPA	Capsule size, colour, mass	Development of fruit and seed structures
Ripening/maturity	18–23+ DPA; pyxidium and dehiscence	Seed moisture, mass, capsule colour	Formation of yield and seed quality
Senescence	Yellowing and drying of leaves	Green-leaf %, capsule maturity	Completion of the life cycle

Sources report an approximately 3.5-month cycle from germination to maturity in P. ovata, although actual duration depends on temperature, photoperiod, water regime, sowing date, and genotype. Therefore, in ontogenetic studies, the onset of senescence should be recorded using objective criteria such as the proportion of yellowing leaves, percentage of mature capsules, and seed moisture content.

CONCLUSION

The ontogeny of Plantago ovata is a sequential biological process beginning with seed imbibition and continuing through seedling and juvenile development, formation of vegetative biomass, reproductive induction, differentiation of the spike-like inflorescence and floral organs, flowering, capsule and seed development, and finally senescence.

Important diagnostic characteristics of reproductive ontogeny include formation of the inflorescence primordium in the axils of relatively older leaves, acropetal and asynchronous flower development within the spike, circumscissile capsule dehiscence, and pronounced differentiation of mucilage-secreting cells in the seed coat.

Calendar time alone is insufficient for studying ontogeny. Recording morphological and phenological markers such as germination, number of true leaves, appearance of the inflorescence primordium, percentage flowering, capsule development by DPA, seed moisture, and senescence provides a more precise scientific framework. Such a system can support comparison of P. ovata biology under different soil and climatic conditions, determination of optimal sowing and harvesting periods, and production of high-quality psyllium seed.

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