IMPACT OF PANNIYUR 1: A MULTIDIMENSIONAL ASSESSMENT

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Foreword

Black pepper holds an esteemed position not only for its historical and cultural significance but also for its substantial contribution to the economy, livelihood and global spice trade. In this context, the variety Panniyur 1, developed by the Pepper Research Station, Panniyur Kerala, stands as a landmark achievement in the annals of black pepper cultivation. The book, Impact of Panniyur 1: A Multidimensional Assessment, systematically explores and documents the far-reaching impacts of Panniyur 1 across agronomic, economic, social and policy dimensions.

While the introduction of a new crop variety is always a significant event, its true measure lies in its sustained, multi-layered impact across farms, markets, and communities. This is precisely where this book, "*Impact of Panniyur 1: A Multidimensional Assessment*", makes its invaluable contribution. This volume traces the journey of Panniyur 1 in India- from its legendary origins to its current domestic and international production scenario. Detailed botanical descriptions and growth requirements provide clarity on the plant's morphology and ecological needs. The genesis of Panniyur 1, including its breeding history, parentage and distinguishing features, is carefully chronicled to highlight its scientific and practical significance. The authors have meticulously employed a balanced methodology, applying expert surveys to capture institutional knowledge and perceived agronomic advantages, farmer surveys to ground the analysis in lived experience, capturing critical data on comparative performance, income gains and on-the-ground management challenges and secondary data analysis to quantify the variety's contribution to national production trends in black pepper.

The study of Impact of Panniyur 1 is more than a mere academic exercise; it is a celebration of agricultural ingenuity and a guidepost for making informed choices regarding investment strategies for crop development. This book is a definitive measure of how one single seed of innovation can change the fate of an entire commodity and the lives of thousands of farmers. The book will serve as a practical blueprint for future varietal development programs in spices, emphasizing the need for meeting farmer expectations regarding varietal traits and product quality attributes.

I commend the authors for undertaking this extensive research survey. The multidimensional view presented here visualizes Panniyur 1 not just as a variety, but as a milestone in India's enduring journey to nurture and enhance its black gold heritage.

09 October 2025   D Prasath

Preface

The journey of black pepper from a precious commodity that powered ancient trade routes to a modern cash-intensive agricultural crop in India is one marked by both immense tradition and continuous innovation. For decades, the sustainability and profitability of pepper cultivation, a primary source of income for numerous small and marginal farmers, particularly in the humid tropics, have been threatened by low yields from traditional varieties and vulnerability to endemic diseases. This environment created a critical need for a technological breakthrough that could redefine the economics of pepper farming.

Panniyur 1, India's first hybrid black pepper variety, developed at the Pepper Research Station, Panniyur, Kerala, represented a watershed moment and promised higher productivity, better adaptability and renewed hope for the pepper farmers. However, the true success of any agricultural innovation is not measured solely at the moment of its release, but by its lasting, real-world impact on the people and the economy it was designed to serve. This realization became the driving motivation behind this study. We felt an urgent need to move beyond historical anecdotes and fragmented data to provide a holistic, evidence-based assessment of Panniyur 1's enduring legacy, over fifty years after its introduction.

The study meticulously integrates three critical data streams: the institutional knowledge gleaned from interviews with leading pepper scientists and experts; the ground reality captured through comprehensive surveys with hundreds of adopting and non-adopting farmers across key growing regions and long-term economic trends derived from secondary data analysis on area, production and trade. By undertaking this multidimensional assessment using expert surveys, farmer surveys and robust secondary data analysis, the study aims to provide an evidence-based evaluation of Panniyur 1's legacy. The methodology section clarifies the data sources, sampling approaches and analytical frameworks employed to ensure a rigorous and comprehensive assessment. Subsequent chapters present nuanced insights from experts and farmer feedback, revealing adoption drivers, productivity gains, challenges and inspirational success stories.

08 October 2025   Authors

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1. The context

Black pepper, often hailed as the "King of Spices," holds a place of significance in Indian agriculture and economy, not only due to its commercial value, and global demand, but also from its historical legacy and cultural associations. It is one of the most widely used and traded spice in the world. The humid tropical evergreen forest bordering the Malabar coast (known as the Western Ghats) is considered to be the centre of origin for black pepper. This region shows the greatest diversity of wild and cultivated forms of black pepper. The Plant is distributed extensively in the moist evergreen forests and to a lesser extent in semi-evergreen and moist-deciduous forests of Western Ghats of South India, growing from almost sea level to an elevation of around 1500 m. From its centre of origin, cultivated black pepper spread to Southeast Asia and other parts of the world, mainly through human migration and trade (Ravindran, 2000). The crop has been intricately woven into the nation's agrarian heritage and trade for centuries. Presently, black pepper thrives as a high-value spice crop under diverse agro-climatic conditions, supporting thousands of small and marginal farmers.

Its significance extends far beyond farm-level income; pepper is a vital component of India's spice export basket, contributing substantially to foreign exchange earnings and strengthening the country's position in the global spice trade. The crop also plays a key role in promoting intercropping systems, and enhancing ecological sustainability, as pepper vines are often trailed on various trees as live standards and are also intercropped with plantation crops like coconut, arecanut, and coffee. Economically, black pepper has driven regional prosperity in states like Kerala and Karnataka, shaping their agrarian economies. The global reputation of Indian pepper for its perceived quality attributes has reinforced India's brand as a spice powerhouse, fostering both domestic and international market linkages. With rising global interest in natural flavours, nutraceuticals, and plant-based health products, black pepper's economic relevance continues to grow, not only as a spice but also as a raw material for value-added industries. The importance of black pepper in Indian agriculture and economy is multifaceted and the crop holds significant latent potential by way of its contribution to exports and as a provider of livelihood security to significant number of small holder producers.

Varietal development efforts have been in the forefront of attempts aimed at increasing the production and productivity of black pepper. Though the country has a rich cultivar diversity in black pepper, several of these cultivars had low yield potential.

However, due to absence of improved varieties these cultivars remained in cultivation in major producing regions like Kerala and Karnataka leading to low productivity in black pepper cultivation. Systematic crop breeding was essential to address the situation by improving the genetic potential of the cultivated black pepper. The first institutional establishment dedicated for research and development of black pepper was initiated, when the Government of Madras started Pepper Research Scheme at Panniyur in the state of Kerala, India in 1949. This establishment, which later became the Pepper Research Station in 1952-53, initially under the Department of Agriculture and later under the Kerala Agricultural University, laid the foundation for modern varietal development efforts in black pepper.

The pioneering research efforts of scientists at Panniyur Research Station led to a series of breakthroughs in pepper breeding. Among them, the most celebrated achievement was the development and release of the World's first hybrid black pepper variety in 1967. Christened Panniyur 1, the variety soon became popular among farmers for its high yield potential and wide adaptability. Nearly six decades after its development, the variety still holds a special place in the hearts of black pepper farmers across the country. Panniyur 1 continues to be a popular varietal choice and has the largest share in black pepper area among all black pepper varieties. Nearing the diamond jubilee of its release, it is important to understand the magnitude and nature of the impact of the variety on black pepper economy as it holds significance for directing and prioritizing the future research efforts in black pepper. With this background, this study analyses the extensive data compiled from agricultural experts and farmers through primary survey and secondary data from authentic sources in an attempt to quantify the impact of the variety Panniyur 1 on the black pepper economy of the country.

Following this introduction, the methodology section outlines the sources of information, data compilation from coordinated varietal trials, and analytical approaches employed to assess varietal performance and economic impact. The results and discussion section presents findings on the yield trends, contribution of Panniyur 1 to the national pepper economy, and the insights derived from expert and farmer surveys. The subsequent sections on key lessons for crop dissemination and policy and research implications synthesize the broader learnings from the Panniyur 1 experience, highlighting its relevance for future crop improvement programs. The bulletin concludes with references and supporting data tables to aid further research and policy formulation.

2. Background of Black Pepper Cultivation

India is one of the major producer, consumer and exporter of black pepper in the world. Black pepper is cultivated to a large extent in Karnataka, Kerala and Tamil Nadu and to a limited extent in Maharashtra, North eastern states like Assam and Meghalaya and Andaman & Nicobar Islands. During 2024-25, the country produced 77,533 tonnes of black pepper from an area of 2,54,597 hectares. Karnataka and Kerala together account for more than 90 per cent of the area and output of black pepper in the country. In Kerala, pepper is mainly grown as a homestead crop, whereas in Karnataka, a significant part of the production comes from plantation-based cultivation.

The yield of black pepper in India has shown fluctuations over the past five decades, though the long-term trend indicates a gradual increase. During the early 1970s, the average yield was around 220 kg/ha, and despite periodic dips, the trendline shows a steady improvement reaching nearly 350 kg/ha by the mid-2020s (Fig 1).
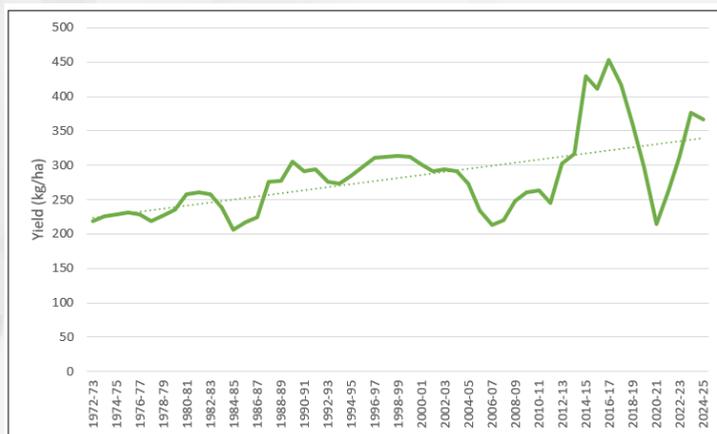
Fig 1: Trend in yield of black pepper in India (TE 1972-73 to TE 2024-25)

From the mid-1980s to late 1990s, yields improved steadily, likely reflecting the adoption of improved varieties and better agronomic practices. However, the period from 2000 to 2010 witnessed stagnation and even declines, possibly due to higher incidence of foot rot disease climate adversities, and aging plantations. Overall, despite short-term volatility, the long-term trend reflects a positive growth in productivity, demonstrating gradual technological progress in varietal technology and crop management.

The pepper production in the country was 26,160 tonnes during 1970-71 from an area of 119960 hectares implying a productivity of 218 kg/ha. To meet the export and domestic demand for black pepper, it was essential to enhance the domestic output as well as the area under crop. The area, production and productivity of black pepper have increased substantially since then. The trends in these important variables affecting the supply of black pepper can be seen from the Table 1, which gives the area, production and productivity of black pepper in India at selected points of time.

Table 1: Trends in area, production and yield of black pepper in India

Year	Area (ha)	Production (Tonnes)	Yield (kg/ha)
TE 1972-73	119463	26160	219
TE 1982-83	110250	28443	258
TE 1992-93	182340	50240	268
TE 2002-03	220900	64960	294
TE 2022-23	297459	92355	391
TE 2023-24	298639	112702	403

Source: Spices Board

The area under black pepper has increased from 119,960 ha in 1970-71 to 259008 ha by 2020-21. Similarly, the productivity of the crop has also increased from 218 kg/ha to 461 kg/ha during this same period. Between 2010-11 and 2020-21, there is a sharp increase in the estimated area and production arising from revised estimation methodology. The enhancement in area and production in pepper was also aided by continuity in research and development activities undertaken by the public sector institutional stakeholders. The state wise area, production and productivity of black pepper during 2024-25 is shown in Table 2.

Table 2: State wise area, production and yield of black pepper in India 2024-25

State	Area (ha)	Production (tonnes)	Yield (kg/ha)
Karnataka	163,667	47,891	293
Kerala	72,669	21,941	302
Tamil Nadu	8,117	1,710	211
Assam	3,739	1,317	352
Meghalaya	1,981	2,267	1,144
Total including others	**254,597**	**77,533**	**305**

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Table 3: Export trends in black pepper from Ind

Year	Export quantity (t)	Export value in nominal prices (Rs Lakhs)
1970-71	17970	1525
1980-81	26364	3895
1990-91	29985	10240
2000-01	21830	38082
2010-11	18850	38319
2020-21	19980	57069
2024-25	20,830	105,500

Table 4: Profile of black pepper exports from India (2024-25)

Item Description	Export value (Rs crore)
Light black pepper	35.1
Black pepper garbled	294.5
Black pepper ungarbled	20.3
Dehydrated green pepper	53.7
Pepper pin heads	1.3
Freeze dried green pepper	9.7
Frozen pepper	0.2
Other pepper (whole)	70.6
Crushed or ground pepper	548.1
Black pepper Oleoresin	533
Black pepper oil	64
Green pepper	0.6
Green pepper in brine	20.8
Total	1652

During 2024-25, the country exported 20,830 tonnes of black pepper valued at 124.54 million US dollars (1,05,500 lakh rupees). This would imply that India exports about a quarter of its domestic output. But it should be borne in mind that during the same period, the country also imported 48,085 tonnes of black pepper for meeting the domestic and industrial demand as well as for the purpose of processing, value addition and re-exporting.

The value chain of black pepper starting from the primary production involves multiple layers and generates several million man-days of employment opportunities. It is estimated that the black pepper and its value-added extracts from India reach more than 150 countries across the globe through sophisticated spice value chains, indicating the high degree of integration of the spice primary production economy of the country with the global markets. The major export destinations of black pepper include the United States, Canada, United Kingdom, Sweden, Germany, UAE and Australia which together account for 67 per cent of the total quantity of black pepper exported from the country.

3. Botanical Description of Black Pepper

Black pepper *(Piper nigrum* L.*)*, popularly known as the "King of spices" or "Black gold" belongs to the family Piperaceae. The genus Piper was first described by Linnaeus in 1753, with the type specimens of *P. nigrum* L. in his "Species Plantarum," and he recognized 17 species in the genus. Later, in 1794, Ruiz and Pavon introduced a second genus, Peperomia. Members of the Piperaceae family are found across tropical and subtropical regions worldwide, inhabiting areas from sea level to mountainous elevations. The family includes over 3000 species in nine genera. A large number of the members of the family are found in two genera, viz, *Piper L.* and *Peperomia* Ruiz and Pav., whose chief centers are Central and South America. Their world distribution has been divided into 12 major centers, one of which is the Indian subcontinent. The taxaonomic classification of Piper nigrum is presented in table 5.

Table 5: Taxonomic classification of *Piper nigrum*

Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Piperales
Family	Piperaceae
Genus	*Piper*
Species	*nigrum*

Pepper has originated in the evergreen forests of the Western Ghats of South India. Wild pepper plants are found extensively in the less disturbed forests, more in the moist evergreen forests, even up to elevations around 1200 to 1500 meters. Cytological studies suggest that the basic chromosome number of Piper is x =13 and that *P. nigrum* with 2n = 52 is tetraploid. A study of the species occurring in Western Ghats indicated that P. nigrum might have originated through hybridization between species with or without polyploidization of the hybrid.

3.1 Morphological Features

Pepper vines, as they grow, exhibit a dimorphic branching pattern, consisting of monopodial, orthotropic shoots and the sympodial, laterally growing plagiotropic fruiting branches. The main orthotropic shoot has indefinite growth and produces lateral fruiting branches from the leaf axils. In addition, the pepper vines produce runners, which are shoots that grow out from the base of the pepper stem. Runner shoots are used as planting material. The leaf characters show wide variation and form a major feature for cultivar identification. The leaf size and shape on the emerging orthotropic shoots and runners differ from normal leaves found in lateral fruiting branches. In pepper leaves, stomata occur only on the lower side of the leaf (hypostomatic). Pepper plants possess adventitious root system as they develop from stem cuttings. Even when plants are grown from seeds, the primary root (tap root) ceases to grow after some time, and further development of the root system is through secondary roots only. Orthotropic growing shoots have climbing roots originating from each node. The inflorescence in black pepper is a glabrous, filiform, pendulous spike-borne opposite the leaves on plagiotropic branches. More than one type of flowers is found usually in a spike, and depending on the flower composition, a cultivar may be predominantly bisexual, pistillate, or staminate. The fruit, although designated by some workers as berry, botanically it is a small drupe. The seed has a small embryo, embedded in a copious endosperm with perisperm.

In the genus Piper, male, female and hermaphrodite forms exist. The cultivated P. nigrum is monoecious having hermaphrodite flowers while the wild ones are mostly dioecious. The cultivars of black pepper might have originated from the wild ones through domestication and selection. More than one hundred cultivars are known and documented, but many of them are disappearing from farmer fields due to reasons like devastation of pepper cultivation by diseases such as foot rot, slow decline and viral diseases and replacement of traditional cultivars with high yielding varieties. Cultivar diversity is rich in Kerala followed by Karnataka. Pepper is predominantly self-pollinated and the pollen dispersal is aided by rain or dew drops and also by gravitational descending of pollen (geitonogamy). The flowers are protogynous, but in the absence of active pollen transfer mechanism, protogyny becomes ineffective ensuring outbreeding.

The pungency of pepper is mainly due to the presence of the alkaloid 'piperine', an yellow crystalline substance. Apart from this, five minor alkaloids possessing pungency has also been identified in pepper extracts (piperettine, piperylin, piperolein A and B and piperanine). The alkaloid is responsible for characteristic biting taste of pepper and amounts to 3-6% of its weight. The commercial oleoresin obtained from pepper, contains compound contributing, both pungency and aroma.

3.2 Growth Requirement

Black pepper, grows well on a wide variety of soils, but prefers well-drained virgin red, lateritic and alluvial soils rich in humus with friable nature and adequate water-holding capacity. In India, it is grown mainly in West Coast tract, where the soils are acidic in nature. The major pepper-growing soils of India can be classified into four orders: Red loam (Alfisols, 70%), forest loam (Mollisol, 10%), laterite (Oxisol, 6%), and alluvium (Entisol, 4%). Increase in productivity of black pepper was noticed with soils having near neutral pH, high organic matter, and high base saturation with Ca and Mg. Black pepper plantations are established on a wide variety of soils with varying texture from sandy loam to clayey loam that are acidic (pH 5.0–6.2) and in coastal sandy soils. Black pepper can be grown successfully from sea level up to 1500 m above Mean Sea Level. It requires humid tropical conditions with little variation in day length throughout the year and cannot tolerate excessive heat and dry spell. In India, black pepper-growing tracts receive 1500 to 4000 mm rainfall in two spells during the southwest monsoon (July to September) and northeast monsoon (October to November) with a peak from July to August. Rainfall after a period of stress induces profuse flowering. Growth of fruit-bearing lateral shoots (plagiotropes) and photosynthetic rate is found highest during peak rainfall period from June to July. Pepper plant prefers a relative humidity of 60 to 95%. The crop tolerates temperature between 10 °C and 40 °C. However, the optimum temperature is 23–32 °C, with an average of 28 °C. Soil temperature of 26 to 28 °C is found to be optimum for root growth of black pepper.

3.3 Pollination

Black pepper is predominantly self-pollinated. While various degrees of protogyny is encountered, the protogyny is ineffective to prevent selfing as the pendant spike is abundantly assured of pollen from the upper flowers, and there will be many spikes dehiscing and releasing pollen grains simultaneously in a vine. The stigma is receptive up to 10 days after emergence, and small quantities of pollen are found in pollen sac even five or more days after dehiscence. Positive geotropism, spatial arrangement of flowers, sequential ripening of the stigma, and nonchronological dehiscence of anthers stimulate selfing. Wind may aid pollen dispersal by agitating the spikes and branches. Predominant form of breeding system in black pepper was geitonogamy and autogamy and not apomixis. Geitonogamic pollination is facilitated by rain and water.

3.4 Propagation

Black pepper is propagated vegetatively. Seed propagation, though possible, is not used because plant is heterozygous in nature, and seedlings raised from seeds will not be of true to type. Rooted cuttings are always used for raising plants. In India, usually runner shoots produced from the base of vine are used for producing rooted cuttings. The length of the cuttings used for rooting varies from 30 to 60 cm consisting of a single node to seven nodes. For direct field planting, lengthier cuttings are preferred. Direct field plating of cuttings results in poor establishments (<5%); hence, cuttings with two or three nodes have to be raised in the nursery initially and transplanted to the main field after attaining rooting and sufficient growth.

3.5 Harvesting and Processing of Black pepper

Black Pepper takes about 180 to 230 days after flowering to reach full maturity. Harvesting is generally done when the berries are fully mature and a few berries starts turning from yellow to red colour in each spike. The stage of maturity at which black pepper is harvested depends on the final value-added product to be prepared. A variety of products can be made from pepper (Table 6).

Table 6: Important products from black pepper

Sn	Major products from black pepper
1	Green pepper in brine
2	Dehydrated green pepper
3	Canned green pepper
4	Freeze dried green pepper
5	Whole black pepper and its powder form
6	Pepper Oil
7	Pepper Oleoresin
8	Piperine
9	White pepper and its powder form
10	Green pepper sauce

For making dried black pepper of commerce, fully mature pepper berries are dried under sun for 3-5 days to obtain whole black pepper. In the modern spice processing unit, black pepper is first passed through a cleaning cum grading unit which consists of a specific gravity separator/destoner for removal of stones, an aspirator for removal of light impurities like the pin heads, husk, light berries, dust etc. and a multiple sieve grader for grading the dried black pepper. The pepper is then passed through a spiral separator (to remove impurities like broken spikes) and then through a magnetic separator (for removal of metallic impurities). The cleaned pepper is graded into different sizes as 4.75 mm, 4.25 mm, 4.0 mm, 3.25 mm etc., The major grades are Tellicherry Garbled Special Extra Bold (TGSEB) (4.8 mm), Tellicherry Garbled Extra Bold (TGEB) (4.2 mm), Tellicherry Garbled (4.0 mm), Malabar Garbled (MG grades 1 and 2) and Malabar Ungarbled (MUG grades 1 and 2). It is then packaged in bulk or consumer packages for domestic or foreign market. There is significant market demand for processed black pepper and its value-added products. The global demand for black pepper is showing an increasing trend, mainly driven by diversified applications across food, flavour, nutraceutical and pharmaceutical and wellness industry. The white pepper of commerce is also a product from the black pepper plant, produced by removing the pericarp (fruit wall) from ripe pepper fruits, which give the buff coloured seeds - the white pepper, which is preferred to black pepper in certain countries.

4. Genesis of Panniyur 1

Vegetative growth, yield, and quality characteristics of black pepper exhibit significant intercultivar variability. The key to the black pepper improvement programme is it's hidden and higher genetic heterogeneity. It is quite interesting, that black pepper has both viable sexual reproduction and vegetative multiplication. Three basic steps are involved in hybridization based genetic improvement. (1) Selection of parents (2) Development of F_1 progeny and (3) Evaluation of superior progeny to be developed into clones (varieties). The first ever hybridization programme in black pepper started in 1959 at Pepper Research Station, Panniyur, Kerala. In 1967, the world's first black pepper hybrid was released under the leadership of Prof. P. K. Venugopalan Nambiar, a Plant Breeder and the Head of the Pepper Research Station, Panniyur (Fig 2). Panniyur 1 is the selection from the hybrid progeny (F_1), cross between a cultivar *Uthirankotta* and *Cheriyakaniakkadan*. The cultivar *Uthirankotta* was used as the female parent and *Cheriyakaniakkadan* as the male parent in the development of Panniyur 1 (Fig 3).*Uthirankotta* is a traditional cultivar from the North Malabar region of Kerala. The flowers in the spikes of the cultivar are predominantly female. The cultivar *Cheriyakaniakkadan* is said to have been in cultivation in Meenachil Taluk of Kottayam. The prominent features of the parents of Panniyur 1 are summarized in Table 7.

Table 7: Characteristics of parents of Panniyur 1

Characteristics	*Uthirankotta (Female parent)*	*Cheriyakaniakkadan (male parent)*
Area of cultivation	North Malabar, Kerala	Kottayam, Kerala
Leaf	Thick leaves	Small, ovate leaves
Spike length	Medium	Short spikes
Fruit setting	Sparse setting	Thick setting

Evaluation of F_1 progenies of many crosses led to the development of the hybrid Panniyur 1. Panniyur 1 is the first ever black pepper hybrid in the World and is internationally recognized for its high yield and wide adaptability.

Fig 2: Prof. P. K. Venugopalan Nambiar, being honoured during an event
(Digitally enhanced version of picture sourced from Sankunny, 1978)

Fig 3: Panniyur 1(Centre) along with its parental lines, Uthirankotta (L) and Cheriyakaniakkadan (R)
(Digitally enhanced version of picture sourced from Joseph, 1981)

4.1 Distinguishing Features

Panniyur 1 has outperformed traditional black pepper cultivars in a very short period of time, making it a preferred choice among farmers. The characteristic features of Panniyur 1 are large and heart shaped leaves, pale yellow coloured shoot tip and long spike with close setting of berries. The young greenish yellow coloured spike of Panniyur 1 has about 99.92% of bisexual flowers, 0.07% of pistillate flowers and 0.01 % of staminate flowers.

The high percentage of bisexual flowers is crucial for good fruit set. Panniyur1 is an early bearing variety and performs well under open conditions and is suitable for all pepper growing regions. When compared to other cultivars, Panniyur 1 produces a greater number of fruiting branches, plagiotropes (laterals), that result into high number of spikes. Other economically important characteristics include long spike, a higher rate of photosynthesis and translocation, and a higher yield per unit area. Studies have also confirmed its suitability for white pepper production because of its bold-sized seeds. Panniyur 1 is now considered as national variety due to all these characteristic features. In all the varietal evaluation studies Panniyur 1 is considered as the National Check variety.

4.2 Institutional Background

A pioneer in the field of research on pepper in the country, Pepper Research Station, Panniyur enjoys a unique position among the Agricultural Research Stations in India. It is the only station solely devoted to the cause of research on black pepper. The station had its humble beginning as a minor scheme started on 23.12.1949 under the then Madras Department of Agriculture. Partly financed by the ICAR, the "Scheme for Scientific Aid to Pepper Industry in South India", started functioning at Mattannur with the intention of starting a research station in that area in due course. But the idea was dropped and the scheme was temporarily shifted to the Agricultural Research Station, Taliparamba in 1950-51. Acquisition of land for the present site of Pepper Research Station, Panniyur was done in 1952-53, which is considered as the year of establishment of the station. Re-organization of states after Indian independence brought the institution under the Department of Agriculture, Government of Kerala on 01.11.1956. Consequent to the formation of the Kerala Agricultural University, the station became a constituent institution of the University from 01.02.1972. Pepper Research Station, Panniyur is located in the Panniyur village of Kurumathur Panchayat in Taliparamba Taluk, Kannur District (Fig 4). The locality receives an average rainfall of 3450 mm per annum.The objective of the station, remains to be the rehabilitation of the Pepper Industry of the country, so as to give it a firm footing and confidence to face competition from other pepper producing countries of the world. An effective technique for controlled pollination and hybridization in pepper plants was developed and perfected at the station for the first time in the history of the crop. Utilizing this technique, a well-planned hybridization programme for the crop was started at the station. The first fruit of this programme was the evolution of the high yielding hybrid variety Panniyur 1, familiar to everyone associated with pepper production.
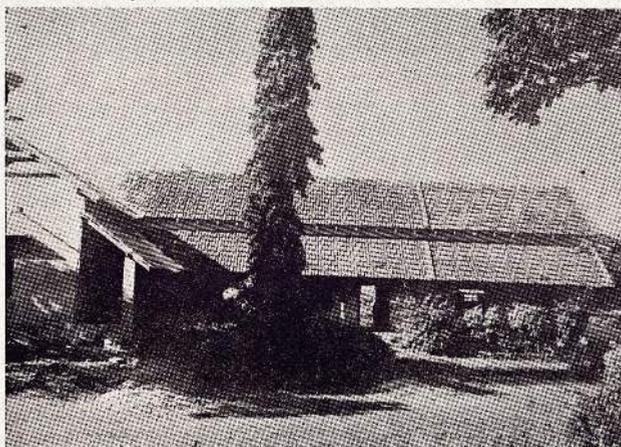
Fig 4: Photograph of Pepper Research Station, Panniyur (circa 1978)

4.3 Yield Potential

Panniyur 1 has played a transformative role among the pepper farming communities ever since its release. Its impact extends beyond agronomic performance, fostering socio-economic growth among pepper farmers by ensuring stable yield and assured income. At present, about twenty-two varieties of black pepper have been released by different research institutes in India. Among the released varieties of black pepper, Panniyur 1 was reported to produce the highest dry pepper yield. Panniyur 1 had recorded an average dry pepper yield of 3,850 kg/ha and potential yield of 8,800 kg/ha, which is 165% higher yield over the parents. The yield attributing characteristics of Panniyur 1 are the longest spike of (17 cm), more spikes per square meter (19), higher berries per spike (125), higher fruit setting percentage (96 %), maximum 1000 green berry weight (155g), and berry volume (145 cc). In Karnataka conditions, variety Panniyur 1 recorded more number of laterals per square metre area (85.66) with maximum fruiting branches, high fresh (10.67 kg) and dry yield (3.66 kg) of berries, higher recovery of white pepper (29.15%), maximum essential oil content (2.95%) and oleoresin (8.78%) than local cultivars. Panniyur 1 recorded the maximum number of spikes per square meter (60.08), which is a positive correlation to the higher yield. Panniyur 1 can also be grown as bush pepper and has recorded an average yield of 1960 kg /ha.

4.4 Resistance/ tolerance to Pest and Diseases

The major bottleneck in Panniyur 1 cultivation is its susceptibility to quick wilt or *Phytophthora* foot rot caused by *Phytophthora capsica*. This fungal infection is a serious threat to plant health and productivity, particularly under high humidity and poor drainage conditions. *The variety* is also sensitive to moisture stress. In experimental trials, Panniyur 1 displayed low relative water content (RWC) in leaves, significantly lower osmotic potential (ψs), and a decline in the ability to synthesize sugars and proline after 15 days of incipient wilting. These properties indicate the susceptibility to prolonged drought conditions. Since Panniyur 1 prefers open conditions for growth and development pollu beetle infestation is relatively low.

5. Methodology of Impact Assessment

Data from both primary and secondary sources were used in the economic impact assessment of Panniyur 1. Primary data from farmers cultivating Panniyur 1 and other pepper varieties were collected following a robust sampling framework

5.1 Sampling Framework

The study was designed to assess the impact of the Panniyur 1 variety of black pepper on farmers across the major producing regions of Kerala and Karnataka, the two leading pepper-growing states of India. A total sample size of 400 farmers was adopted for the survey. The rationale for the sample size is based on statistical sampling theory, where the minimum required sample size for large populations is calculated using the formula:

$$n = \frac{Z^2 * p * (1-p)}{e^2}$$

where,

- n = Required sample size,
- ZZZ = Z-score corresponding to the desired confidence level (1.96 for 95% confidence),
- p = Estimated proportion of the population. In this study we used 0.5 is used as the true proportion is unknown while providing the maximum variability, and
- e = Acceptable margin of error (0.05 for ±5%).

Substituting these values:

$$n = \frac{(1.96)^2 * 0.5 * (1-0.5)}{(0.05)^2}$$

Thus, a sample of approximately 384 farmers is statistically adequate to ensure reliable estimates with 95% confidence and 5% precision. To account for non-response and to round the sample for field practicality, the final sample size was fixed at 400 farmers. The total sample of 400 was apportioned between Kerala and Karnataka in proportion to their respective shares of area under black pepper cultivation. According to official statistics, Karnataka accounts for 1,63,667 ha (69.2%) and Kerala for 72,669 ha (30.8%) of the total black pepper area in these two states. Accordingly, the farmer sample was distributed between Karnataka (277 farmers, 69.2%) and Kerala (123 farmers, 30.8%). Within each state, the top three pepper-growing districts were selected, accounting for the largest shares of cultivated area.

- Karnataka: Kodagu (99,979 ha; 46.3%), Chikkamagaluru (50,266 ha; 23.3%), and Hassan (35,639 ha; 16.5%).
- Kerala: Idukki (37,202 ha; 50.5%), Wayanad (8,956 ha; 12.2%), and Kannur (3,968 ha; 5.4%).

The farmer samples were further apportioned across these districts in proportion to their area share under black pepper to ensure representativeness.A multi-stage sampling design was employed. In the first stage, the major pepper-growing districts within each state were purposively selected. In the second stage, lists of black pepper growers were compiled from multiple sources, including the Directorate of Arecanut and Spices Development (DASD), ICAR-Indian Institute of Spices Research (IISR), State Agriculture Departments, and farmer collectives. From these district-level farmer lists, Simple Random Sampling (SRS) was used to select respondents proportionately to district-wise allocations. Primary data were collected from the selected 400 farmers using a structured and pre-tested questionnaire. The questionnaire covered aspects such as adoption history of Panniyur 1 by the farmer, relative yield advantage, farmers' perceptions on various aspects of the variety, and spread of the variety in the locality.

5.2 Expert Survey

A separate schedule was developed for collecting information from experts with long term experience (more than 10 years) in research and development ecosystem of black pepper crop. Data from 30 such experts representing major agro-climatic regions growing black pepper were used to develop the estimates on spread of Panniyur 1 variety across the country and to validate the findings from the farmer surveys. Secondary data from authentic sources like Spices Board of India, Directorate of Economics and Statistics, Department of Agriculture, Government of Kerala and Department of Horticulture, Government of Karnataka were used to gather data on area, production and productivity of black pepper, price of the produce and share of the states in black pepper output of the country.

5.3 Data From Coordinated Varietal Trials

The Coordinated Varietal Trials (CVT) on black pepper conducted under the All India Coordinated Research Project on Spices (AICRPS) provides an alternate source of data on yield advantage of the variety Panniyur 1. These trials are regularly conducted at designated centres of the AICRPS as a prerequisite for generating data for development and testing of new varieties. Panniyur 1 has been one of the entries in these CVTs as a National Check Variety. Therefore, CVTs provide comparative yield data on Panniyur 1 and other varietal entries.

The data from CVTs on black pepper was compiled from various annual reports of the AICRPS, which summarizes the yield data of the CVT trials. Pooled data for the period 2009-14 and 2012-18 from two Coordinated Varietal Trials (CVT started in 2000 (5 locations) and 2006 (6 locations) respectively) and yearly data from CVT started in 2015 was also used in the analysis. The summary of the CVT data used in the study is presented in Table 8.

Table 8: Summary of Coordinated Varietal Trial data sources

Trial	Entries	Locations	Data description
CVT 2000	13	5	Pooled data for 5 years from 2009-2014
CVT 2006	10	6	Pooled data for 6 years from 2012-2018
CVT 2015 series	9-11	1	Yearly data from 6 locations for the period 2018-2021 where Panniyur 1 was included as a National Check (Total 14 comparative varietal trial data)
CVT - 2015- Farmer var.	4	1	Yearly data from 5 locations for the period 2018-2023 where Panniyur 1 was included as a national Check (Total 8 comparative varietal trial data)

Notes: The number of varietal entries varied across the years and locations as new entries were allowed after the trials had been initiated.

The data for the years/locations where data of yield of Panniyur 1 is not available were omitted. Thus, information from 24 experimental instances were included in the study. The average yield from Panniyur 1 was compared against the pooled average yield of all the other varieties included in the trial for each varietal-trial data set. This data was used to scientifically validated comparison of yield between Panniyur 1 and other black pepper varieties.

5.4 Cronbach's Alpha

Cronbach's alpha was computed for the items under the varietal dimensions to assess their reliability and internal consistency in measuring the opinion of farmers regarding the variety, Panniyur 1. The value of Cronbach's alpha ranges between 0 and 1 and is calculated using the formula:

$$\alpha = \frac{N}{N-1}\left(1 - \frac{\sum Var(item)}{Var(total\ score)}\right)$$

In general, values above 0.9 indicate excellent reliability, while values below 0.6 suggest poor consistency in measuring the farmers' perceptions of Panniyur 1.

5.5 Modified Net Promoter Scores

To capture farmers' perception of the Panniyur 1 black pepper variety, the Net Promoter Score (NPS) framework was applied with modifications suited to the agricultural context. Farmers were asked to rate, on a scale of 0 to 10, how likely they were to recommend the variety to other farmers based on its overall performance. The conventional NPS classification (promoters: 9–10; passives: 7–8; detractors: 0–6) was modified in this study, with scores of 8–10 designated as promoters (indicating strong endorsement), 6–7 as passives (indicating moderate satisfaction), and 0–5 as detractors (indicating low likelihood of recommendation). The categories were adjusted to account for the inherent variability in farming systems and the influence of several uncontrollable factors such as weather, pest incidence, and management practices, which can affect farmers' evaluation of a variety. The revised thresholds are therefore considered more appropriate for capturing a realistic measure of varietal endorsement in the farming context. The NPS was then calculated as the percentage of promoters minus the percentage of detractors, providing a more realistic measure of farmer endorsement.

5.6 Economic Impact of The Variety

The varietal spread of Panniyur 1 at the national level was estimated from the expert survey was used along with the estimated yield advantage other varieties calculated based on data from Coordinated varietal Trials in calculating the economic impact of the variety. Using a logical framework, an estimate of the national average yield in the event of absence of Panniyur 1 was developed. The counterfactual scenario was constructed by assuming that the area under black pepper would have remained same even if Panniyur 1 was not developed. The data on area, production and yield of black pepper in India along with the wholesale price of the commodity was sourced from the Spices Board, while the value of output was obtained from the National Accounts Division, National Statistical Office, Ministry of Statistics and Programme Implementation (2025).

6. Results and Discussion

6.1 Varietal Dissemination and Adoption

Panniyur 1 is the most popular variety among the released varieties of black pepper. Of the total 152 blocks in Kerala surveyed for black pepper cultivation, 28 blocks were recorded to be dominated by the variety Panniyur 1. The information compiled from experts provides an estimate of the spread of the variety across the country. Presently, the average share of the variety Panniyur 1 in total area under black pepper cultivation was 58.7 per cent at the national level. The share of Panniyur 1 was highest during the period 1990 to 2000. Since then, the share of Panniyur 1 has declined slightly. The area share of Panniyur 1 in black pepper area was assumed to be constant during the last decade for the purpose of economic impact estimation.

6.2 Factors Influencing Popularity of The Variety Panniyur 1.

An agreement index was constructed from the responses obtained from black pepper experts on various factors resulting in the popularity of the variety Panniyur 1 by assigning weights (Strongly agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly disagree = 1) to their responses.

Table 9: Ranking of factors influencing popularity of Panniyur 1

Rank	Factor	Mean Score
1	Yield advantage over other black pepper varieties	4.56
2	The robust growth and vigour of the plant	4.5
3	Input responsive nature of the variety	4.44
4	Institutional support for the variety	4.19
5	Adaptability to various pepper growing tracts	4
6	Adaptability to rapid multiplication	3.81
7	Absence of alternate varietal choices in pepper	2.94
8	Resistance to pest and diseases	2.44

The mean scores for each factor were calculated after confirming that the factors included in the study reliably measure the popularity of the variety using Cronbach's alpha. The Cronbach's alpha (0.65) indicated that the factors included were consistent with the objective. The statements ranked in the order of the mean scores obtained are presented in table. The yield advantage and the robust growth and vigour of the plant were perceived as most influential among all factors in making the variety popular.

The results indicate strong expert consensus on attributes such as yield advantage, robust growth and vigour, input responsiveness, institutional support and adaptability to rapid multiplication, all of which received mean scores above 4.0 (Table 9). In contrast, absence of alternate varietal choices received mixed views, with many experts opting for a neutral response, suggesting moderate agreement. The lowest score was recorded for the "resistance to pests and diseases" where a significant proportion of experts disagreed, indicating that this factor is a not a major factor in making Panniyur 1 a popular choice among farmers.

6.3 Farmer Survey Findings

A paired t-test was conducted to compare the yields of Panniyur 1 and local black pepper varieties across 300 paired observations, where the farmers cultivated both Panniyur 1 and other varieties within the same farm. The results showed that the mean yield of Panniyur 1 (2.74 kg/vine) was significantly higher than that of local varieties (1.81 kg/vine). The mean difference of 0.94 kg/vine was statistically significant ($t(299) = 13.61$, $p < 0.001$), indicating that adoption of Panniyur 1 provides a clear yield advantage to farmers (Fig 5).
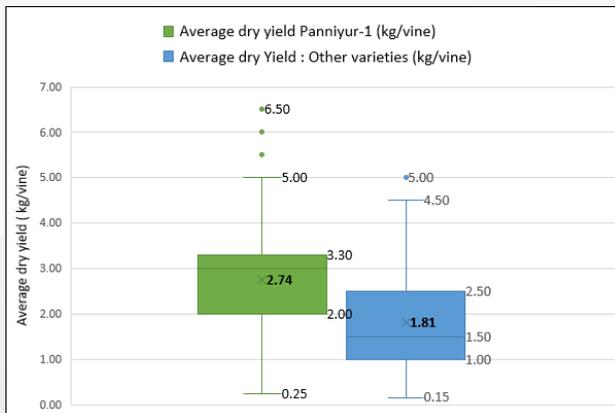

Fig 5: Box plot of yield distribution across Panniyur-1 and other varieties

Table 10: Summary of farmer responses on satisfaction dimensions of Panniyur 1

Varietal dimensions	Mean score	Per cent respondents (N= 300)				
		Very Unsatisfied	Unsatisfied	Neutral	Satisfied	Very Satisfied
Spike length & size of the berries	4.27	0.7	2.7	8	46.7	42
Availability of planting material	4.07	1.3	4.3	8	58.7	27.7
Market acceptance of the produce	3.93	1	1	17	65.7	15.3
Yield advantage over other varieties	3.88	1.7	3.3	16.3	62.7	16
Response to fertilizers/ manures	3.85	2	2.7	16.3	66.3	12.7
Pest and Disease resistance	2.85	17.7	26.3	22.3	20.7	13

Cronbach's Alpha = 0.73

The analysis of farmer responses on various satisfaction dimensions of Panniyur 1 pepper variety shows a generally positive perception, with higher mean scores observed for spike length and berry size (4.27), availability of planting material (4.07), and market acceptance (3.93) (Table 10). Yield advantage (3.88) and response to fertilizers/manures (3.85) were also rated favourably, indicating that farmers recognize the production and market potential of the variety. However, pest and disease resistance received a relatively lower mean score of 2.85, reflecting a key area of concern. The distribution of responses further highlights that the majority of farmers were satisfied or very satisfied with most traits, particularly market acceptance and spike characteristics, whereas dissatisfaction was more pronounced in relation to pest and disease tolerance. The reliability of the scale was confirmed with a Cronbach's alpha of 0.73, which falls within the acceptable range, suggesting that the set of items consistently measured farmers' satisfaction with the varietal attributes.

The Net Promoter Score (NPS) analysis revealed a strongly positive perception of the Panniyur 1 black pepper variety among farmers. Out of the 400 respondents, 65.3% rated the variety in the promoter category (scores 8–10), indicating a high level of endorsement.

A further 20.7% of farmers fell into the passive category (scores 6–7), reflecting moderate satisfaction, while only 14% were detractors (scores 1–5), indicating limited likelihood of recommendation. The resulting NPS of 51.3 demonstrates a robust level of farmer support for the variety, suggesting that Panniyur 1 enjoys broad acceptance and confidence within the farming community (Table 11).

Table 11: Summary: Net Promoter Scores

Rating	Frequency of responses	Per cent share of responses (%)
1-5	56	14
6-7	83	20.7
8-10	261	65.3
Net Promoter Score	**51.3**	

6.4 Secondary Data Analysis

The item "availability of planting material" was ranked second with a mean score of 4.07 indicating that the easy availability of planting material played a positive role in the spread of the variety. The experts' opinion also highlighted the role of "Institutional support for the variety" as an important factor leading to the popularity of Panniyur 1. After the development of the variety, the Pepper Research Station (PRS) ensured that the planting material of the variety was available to the farmers in sufficient numbers. The availability of rapid multiplication technique for black pepper and focused institutional support for the variety are evident in the planting material production undertaken by the Pepper Research Station during the initial years following the release of the variety. The data on the planting material of Panniyur 1 produced by the PRS during 1968-69 to 1990-91 is given in Table 12.

The cumulative number of planting units of Panniyur 1 distributed to the farmers from the PRS crossed one lakh figure within a short period of 10 years and further crossed the five lakh mark in less than another decade. The other research stations of the Kerala Agricultural University (KAU) also helped in rapid dissemination of the varieties. Presently, apart from the Pepper Research Station at Panniyur, The Regional Agricultural Research Station at Ambalavayal, Wayanad district and Department of Spices and Plantation, Thrissur are the two major sources of production of Panniyur 1 planting material. The planting material produced by these three units during the last ten years is provided in Table 13.

Table 12: Production of Planting material of Panniyur 1 from PRS (1968-69 to 1990-91)

Year	Planting material production (Panniyur 1)	Cumulative Nos of Planting material (Panniyur 1)
1968-69	4948	4948
1969-70	4803	9751
1970-71	7799	17550
1971-72	11518	29068
1972-73	9306	38374
1973-74	11386	49760
1974-75	16033	65793
1975-76	10567	76360
1976-77	16314	92674
1977-78	61677	154351
1978-79	84319	238670
1979-80	43162	281832
1980-81	40732	322564
1981-82	34228	356792
1982-83	21701	378493
1983-84	21921	400414
1984-85	28422	428836
1985-86	39305	468141
1986-87	53024	521165
1987-88	62711	583876
1988-89	44025	627901
1989-90	28212	656113
1990-91	30937	687050

Source: Farm records of Pepper Research Station, Panniyur (various years)

Table 13: Planting units (P1) supplied by selected centres of KAU (2014-15 to 2024-25)

Year	PRS, Panniyur	Dept of Spices & Plantation crops	RARS, Ambalavayal	Total	Cumulative
2014-15	73952	10804	215650	300406	300406
2015-16	76000	30955	218170	325125	625531
2016-17	84410	14231	194341	292982	918513
2017-18	40494	14331	226007	280832	1199345
2018-19	80000	12290	298776	391066	1590411
2019-20	82302	5186	141686	229174	1819585
2020-21	56563	9054	175240	240857	2060442
2021-22	88286	7095	293190	388571	2449013
2022-23	62596	8649	233641	304886	2753899
2023-24	73805	8244	247524	329573	3083472
2024-25	108676	9820	228087	346583	3430055

The average planting material production has remained above three lakhs during the last ten years indicating the continued demand for Panniyur 1 among the pepper farmers. The institutional interventions in establishing a robust planting material delivery system have played a stellar role in promoting the variety. The availability of authentic quality planting material soon paved the way for private initiatives in planting material production and also for farmer-to-farmer spread of the variety. During the last ten years alone, more than 34 lakh planting units of the variety Panniyur 1 were distributed to the primary producers from the three centres of the Kerala Agricultural University. The absence of strong enforcement of intellectual property rights over the variety by the developing institution, which was the prevailing practice at the time of its development, might have played a positive role in fast spread of the variety.

6.5 Impact of Panniyur 1 on Black Pepper Economy of India

Based on the expert survey, it was estimated that 58.7 per cent of the total area under black pepper in India was occupied by the variety, Panniyur 1. The data from the CVT's were used to estimate the relative yield advantage of the variety in comparison to other black pepper entries included in the trials selected for the analysis. Data on the performance of Panniyur 1 and other black pepper varieties were compiled from coordinated varietal trials (CVTs) conducted across multiple research centres and years. The dataset comprised 24 paired observations representing mean yield or related performance indicators from identical test environments. Descriptive statistics were computed to summarize variability, and the results indicated relatively high coefficients of variation (78–82%), reflecting the wide range of agro-climatic and management conditions under which the trials were conducted. Despite this inherent variability, a paired t-test was employed to assess the consistency of performance differences between Panniyur 1 and other varieties. The test revealed a statistically significant advantage for Panniyur 1 ($t = 4.55$, df = 23, $p < 0.001$), confirming its superior and stable performance across diverse environments. The high correlation between paired values ($r = 0.96$) further indicated that environmental effects were largely common across varieties, lending confidence to the observed varietal differences. The mean yield enhancement of Panniyur 1 over varieties in the CVTs was estimated to be 35.6 per cent.

The estimates of varietal spread (58.7 %) and relative yield advantage (35.6 %) were used in the logical framework to estimate the variables of interest (Table 14). The data for the period 2015–16 to 2024–25 clearly demonstrates the significant contribution of Panniyur 1 to the black pepper economy. During this period, India had an average area of 2.37 lakh hectares under black pepper cultivation, producing about 75,914 tonnes annually with an average yield of 332.7 kg/ha. Panniyur 1 accounted for nearly 58.7% of the total area (about 1.39 lakh ha) and contributed an estimated 65.8% of the total national output, producing around 49,981 tonnes per year. The yield advantage of Panniyur 1 is substantial—its estimated average yield of 373.1 kg/ha is considerably higher than the national mean. Without Panniyur 1, the estimated national output would have been only 62,792 tonnes, implying an incremental production of 13,122 tonnes per year attributable to this single variety. This productivity gain translates into an estimated increase of 57.5 kg/ha in the national average yield.

In economic terms, the contribution of Panniyur 1 is equally impressive. The value of output from this variety is estimated at ₹2,633 crore per year at 2024–25 wholesale prices, or ₹2,685.07 crore based on the actual realized value of output. The incremental output value generated by Panniyur 1 is estimated at ₹831.86 crore per year (at wholesale prices) or ₹691 crore per year (at actual realized values).

Overall, the pivotal role of Panniyur 1 in sustaining India's black pepper economy, can be gauged from these impact dimensions. Its widespread adoption, superior yield potential, and economic contribution also bring out the importance of focused varietal improvement and dissemination efforts in spice crops.

Table 14: Annual contribution of Panniyur 1 to national pepper economy

Particulars	Value
Average Area: 2015-16 to 2024-25	2,36,879 ha
Average Production: 2015-16 to 2024-25	75,914 tonnes/year
Average Yield: 2015-16 to 2024-25	332.7 kg/ha
Share of Panniyur 1 in area under black pepper	58.70%
Average area under Panniyur 1	1,39,048 ha
Estimated average yield of Panniyur 1	373.1 kg/ha
Estimated black pepper output from Panniyur 1	49,981 tonnes/ year
Estimated impact of Panniyur 1 on National average yield	57.5 kg/ha
Counterfactual black pepper output (absence of Panniyur 1)	62,792 tonnes/year
Incremental black pepper production due to Panniyur 1	13,122 tonnes/year
Value of output from Panniyur 1 (Wholesale prices, 2024-25)	₹ 3,168.5 Crores/year
Value of output from Panniyur 1 (Actual value of output)	₹ 2,632.5 Crores/year
Share of Panniyur 1 in black pepper output	65.80%
Value of incremental output (Wholesale prices, 2024-25)	₹ 831.9 Crores/year
Value of incremental output (Actual value of output)	₹ 691.1 Crores/year

Note: The black pepper output was measured using two approaches. The first one uses the average annual wholesale price of black pepper for the year 2024-25 for black pepper. The average of two major wholesale markets in Kerala and Karnataka (Cochin and Sirsi, respectively) were used in valuing the output. In the second approach, the actual value of output of black pepper as estimated by National Accounts Division, Ministry of Statistics and Programme Implementation, Government of India for various years was used to calculate the actual realized value of black pepper by the farmers.

7. Key Lessons for Crop Dissemination

The experience from the dissemination of Panniyur 1 black pepper variety provides valuable insights for designing future varietal development and diffusion programs. The foremost among them is that the success of a crop variety hinges on the presence of superior and desirable traits that can influence farmer perceptions about varietal performance while meeting the genuine demands of the market. Panniyur 1 offered a significant yield advantage, with potential yields of up to 8,800 kg/ha—about 165% higher than its parental lines—and had the additional benefit of early bearing. Its wide adaptability to diverse agro-climatic conditions made it suitable for cultivation across all major black pepper-growing regions. This adaptability, coupled with high market preference, ensured both rapid adoption and sustained profitability, underscoring that varietal innovation must be demand-driven and closely aligned with farmer and market expectations.

Equally critical to its success was the institutional support system that underpinned dissemination. The Pepper Research Station (PRS), Panniyur, along with other centres of the Kerala Agricultural University and Private entrepreneurs involved in planting material production played a pivotal role by ensuring the availability of authentic and quality planting material across the black pepper growing regions of the country. Experts identified this institutional backing as a decisive factor in the variety's popularity. The use of rapid multiplication techniques developed at PRS enabled large-scale production and timely supply of planting material, effectively overcoming one of the most common bottlenecks in varietal dissemination—limited access to genuine propagating stock. This experience highlights that even a superior variety cannot achieve impact unless supported by a robust institutional mechanism for quality material delivery and farmer outreach.

A third lesson concerns the enabling policy environment that allowed fast and widespread dissemination. At the time of its release, the absence of stringent enforcement of intellectual property rights (IPR) over planting material catalyzed private sector involvement in planting material production. In an economic environment of low economic growth, the absence of overhead charges for intellectual property rights facilitated entrepreneurial intent in propagation of the variety commensurate with farmers demand for the variety. While such a situation may not align with modern IPR frameworks or prevailing economic growth scenario, it proved advantageous for early diffusion and adoption. The case illustrates that flexible or supportive policy contexts can significantly accelerate the reach of promising technologies during their initial dissemination phase.

However, the success story also brings to light a cautionary lesson for future programs. Despite its many strengths, Panniyur 1 exhibited vulnerability to major diseases such as quick wilt or Phytophthora foot rot. Farmers expressed relatively low satisfaction with the variety's pest and disease resistance, indicating that long-term sustainability requires continuous focus on enhancing biotic and abiotic stress tolerance. Ensuring resilience in new varieties is essential to maintaining productivity gains and minimizing economic risks associated with environmental or disease pressures.

In this context, the experience of Panniyur 1 reinforces the importance of continuous varietal improvement as a strategic imperative. A single successful release should serve not as a conclusion but as a foundation for further innovation. The unique genetic base and performance traits of Panniyur 1 provide opportunities for future breeding programs to develop improved derivatives with enhanced resistance, quality, and adaptability. Maintaining a dynamic pipeline of improved varieties will help sustain productivity growth, preserve market competitiveness, and ensure the long-term vitality of the black pepper sector.

In summary, the dissemination of Panniyur 1 demonstrates that successful varietal spread requires an integrated approach—combining superior genetic traits, strong institutional delivery systems, supportive policies, and continuous research feedback. These lessons form a replicable model for promoting future crop varieties that can achieve both widespread adoption and enduring impact across India's diverse farming systems.

8. Policy and Research Implications

The experience of *Panniyur 1*—the world's first hybrid black pepper variety—offers far-reaching lessons for research strategy, institutional design, and policy formulation in crop development and dissemination. Its success underscores the transformative potential of targeted scientific innovation, institutional commitment, and enabling policy frameworks in accelerating agricultural progress.

8.1 Prioritize Hybridization and Genetic Breakthroughs

The development of Panniyur 1 marked a scientific milestone in black pepper research, achieved through pioneering work in controlled pollination and hybridization at the Pepper Research Station (PRS), Panniyur. This breakthrough resulted in a variety with a yield potential 165% higher than its parents—demonstrating the immense payoff of bold, innovative breeding efforts.

Future research strategies must prioritize high-risk, high-reward breeding programs that embrace hybridization and genetic heterogeneity as the foundation for major productivity gains. Incremental improvements achieved through selection alone cannot deliver the transformative changes required in today's competitive and climate-challenged agricultural environment. Public funding agencies should thus allocate dedicated resources to frontier breeding research in spices and other high-value crops.

8.2 Mandate Long-Term Trait Diversification for Sustainability

The long-term sustainability of black pepper requires continued efforts in diversifying the varietal features, maintaining its quality, tackling emerging challenges like biotic stresses and climatic vagaries, and promoting scientific farming practices among farmers. While Panniyur 1 revolutionized black pepper cultivation, its vulnerability to *Phytophthora* foot rot and other biotic stresses revealed a critical gap in long-term varietal sustainability. Overreliance on a single genotype increases production risks and limits resilience to evolving pest and disease pressures. Sustained genetic diversification is essential for ensuring the long-term sustainability of black pepper cultivation. Future breeding programs must focus on integrating disease resistance, moisture stress tolerance, and climate resilience. The next generation of varieties should combine yield superiority with robustness against abiotic and biotic stresses to secure farmer income and safeguard productivity against climate variability.

8.3 Sustain Focused Institutional Investment in Specialized Research

The origin of *Panniyur 1* is directly linked to the visionary establishment of the Pepper Research Station at Panniyur in 1952–53—the only dedicated black pepper research station in India. Its focused mandate and long-term institutional stability created an ecosystem for scientific excellence and innovation. The success of *Panniyur 1* reinforces the need for continued investment in specialized, research stations for economically significant commodities like spices. Public policy must ensure long-term funding, infrastructure, and talent retention within such institutions. Concentrated institutional focus fosters depth of research, continuity in sectoral development efforts including varietal development initiatives, and the generation of globally competitive institutions and innovations.

8.4 Develop a Proactive and Scalable Planting Material Delivery System

The dissemination of Panniyur 1 was not only a scientific achievement but also an institutional success story. The PRS ensured timely availability of authentic planting material in adequate quantities, supported by the adoption of rapid multiplication techniques. This institutional readiness bridged the gap between varietal release and field-level adoption, enabling both organized and farmer-led diffusion. Extension and seed policies must embed a structured planting material delivery mechanism as an integral part of varietal release strategies. A coordinated model linking research institutions, nurseries, and farmer networks is essential for large-scale and reliable dissemination. Institutional distribution systems should also encourage private sector participation and farmer-to-farmer sharing to enhance the speed and reach of varietal spread.

The journey of Panniyur 1 illustrates the powerful synergy between scientific innovation, institutional focus, and supportive policy. Its success provides a replicable framework for future crop improvement initiatives: invest boldly in hybridization research, diversify for sustainability, institutionalize benchmark standards, sustain specialized research capacity, and integrate planting material logistics into varietal dissemination. Together, these strategies can help achieve transformative, inclusive, and resilient growth in India's spice sector and beyond.

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IMPACT OF PANNIYUR 1: A MULTIDIMENSIONAL ASSESSMENT

ICAR- All India Coordinated Research Project on Spices
ICAR- Indian Institute of Spices Research
Kozhikode, Kerala.