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# Production Technology
## of Quality Protein Maize (QPM) and its Nutritional Value for Human Consumption

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**Abstract**

The article highlights the significance of Quality Protein Maize (QPM) in addressing global nutritional challenges, with a focus on its development and adoption in India. QPM, enriched in lysine and tryptophan, addresses deficiencies in conventional maize contributing to improved protein quality. The evolution from opaque-2 mutants to QPM hybrids is discussed, emphasizing the role of the All India Coordinated Research Project on Maize and CIMMYT in this transformation. The versatile uses of QPM, spanning human and animal nutrition, are underscored, along with its potential for rural entrepreneurship. The article delves into production technology, cultivar selection, soil preparation, and fertilizer management for QPM, offering a comprehensive guide for farmers. It also addresses challenges in seed production and advocates for integrating QPM into broader agricultural policies for sustainable growth and global nutritional excellence.

**Introduction**

Maize (*Zea mays* L.) holds the distinction of being the third most extensively cultivated crop globally, thriving in tropical, sub-tropical, and temperate regions from the equator up to elevations exceeding 3000 meters under various conditions ranging from irrigated to semi-arid. Renowned for its productivity, maize stands out as the most productive cereal on a global scale, benefiting from a remarkably high genetic diversity that positions it favorably to address emerging challenges. This versatile crop serves as a vital staple food in numerous countries across Latin America, Africa, Asia, and beyond.

In the context of India, maize assumes a crucial role as a grain cereal crop, covering an expansive cultivation area of 8.5 million hectares. With an annual production of 21 million metric tons and a productivity of 24 quintals per hectare, maize contributes approximately 9% to the country's food basket. Remarkably, 80% of its cultivation occurs as rainfed crops. Within India, maize serves diverse purposes, with 21% being directly consumed as food, 63% utilized for poultry, fish, piggery, and livestock feed, around 12% involved in milling and brewery industries (including starch, oil, and dry milling), and the remaining 1% dedicated to seed production.

Maize kernels serve as a rich source of essential nutrients, including carbohydrates, fats, proteins, vitamins, and minerals. On average, they comprise 14.9% moisture, 11.1% protein, 3.6% fat, 2.7% fiber, 66.2% other carbohydrates, and 1.5% minerals. The protein composition of the kernel is diverse, consisting of five fractions: albumin (7%), globulin (5%), non-protein nitrogen (6%), prolamine (60%), and glutelin (25%), with the remaining 5% being residual nitrogen. In many developing countries, particularly in Sub-Saharan Africa (SSA), maize plays a crucial role in meeting the dietary protein and calorie requirements of millions, contributing to over 30% of total dietary protein and more than 20% of daily energy in SSA. Termed as a "nutri-cereal," maize is considered nutritious for human consumption.

However, conventional maize faces challenges due to the deficiency of zein in two essential amino acids, lysine and tryptophan. The predominance of zein imparts a low biological value and reduced digestibility to conventional maize, causing an imbalance in niacin biosynthesis and, consequently, poor net protein utilization in maize genotypes. The identification of a naturally occurring maize mutant, opaque 2 (o2), in Connecticut maize fields in 1920 marked a significant breakthrough. Homozygous o-2 mutants exhibited double lysine and tryptophan contents, sparking enthusiasm among researchers for genetic manipulation of maize protein quality. Subsequent discoveries of various mutant types with altered amino acid compositions further fueled hopes for enhancing maize's nutritional profile.

The opaque 2 gene remained the primary target for breeding nutritionally enriched maize. This gene was introduced into numerous varieties and inbred lines using backcross breeding and other methods. Opaque Quality Protein Maize (QPM) varieties were developed and released for cultivation in various regions, including African countries, Latin America, and India. In India, the All India Coordinated Research Project on Maize played a pivotal role, leading to the development and release of three opaque-2 Open-Pollinated Varieties (OPVs) for cultivation. While the o2 mutation brought about positive outcomes by reducing zein synthesis and increasing lysine and tryptophan levels in endosperm protein, it also exhibited various deleterious pleiotropic effects. These effects included a soft chalky endosperm, diminished dry matter accumulation, resulting in decreased grain yield, and a dull soft chalky kernel phenotype that heightened susceptibility to ear rots and stored-grain pests. Additionally, there was a slower field drying process following physiological maturity, rendering such varieties less popular. Under the leadership of Dr. S.K. Vasal, a World Food Laureate, and his team at CIMMYT (International Maize and Wheat Improvement Center), various endosperm modifier genes were identified. These genes proved instrumental in favorably altering grain characteristics, addressing a crucial obstacle in promoting high lysine/tryptophan opaque-2 maize. The resulting germplasm was termed Quality Protein Maize (QPM), featuring the opaque 2 gene along with the hard endosperm He gene (conferring kernel vitreousness), genetic modifiers with similar, small, supplementary effects, and biochemically, high tryptophan (>0.6%) and high lysine (>2.4%), balanced leucine to isoleucine ratio, lower zeins, and a corresponding increase in the non-zein fraction in endosperm proteins (Table 1).

In QPM, zein concentration is reduced by 30 percent, leading to increased lysine and tryptophan content compared to conventional maize. The lower leucine content in QPM further balances the ratios of leucine to isoleucine (Table 1). This balanced composition of essential amino acids in QPM enhances the biological value of its protein. While the true protein digestibility of maize versus QPM is nearly the same, the biological value of QPM is double compared to traditional maize varieties. Despite its enhanced nutritional profile, QPM maintains the appearance and taste of normal maize. The global recognition of QPM's development signifies a significant step toward addressing nutritional security for economically deprived sections of society.

**Table No. 1** Quality Comparison on Biochemical Parameters in QPM and Normal Maize

| Quality Parameter | QPM | Normal Maize |
|---|---|---|
| **Tryptophan** | 0.6 or more | 0.3 or less |
| **Prolamine** | 22.5 | 47.5 |
| **Lysine** | 2.5 or more | 1.25-1.50 |
| **Globulins** | 4.0 | 1.5 |
| **Albumins** | 13.2 | 3.2 |
| **Glutelin** | 50.10 | 35.20 |
| **Isoluecine** | 1.93 | 2.16 |
| **Leucine** | 5.07 | 8.27 |
| **Protein** | 92 | 84 |
| **Biological value** | 80 | 42 |

The Directorate of Maize Research persistently engaged in activities aimed at acquiring, adapting, and selecting exotic Quality Protein Maize (QPM) germplasm from sources like CIMMYT and others. This germplasm was then strategically utilized in the development of new maize varieties through a meticulous breeding process. In this pursuit, the introduction of Shakti 1, a QPM variety, marked a significant milestone. This particular variant, having undergone thorough development, was recommended for release in farmers' fields in the year 1997.

The evolution of the agenda within the agricultural research landscape witnessed a shift from Open-Pollinated Varieties (OPVs) and multi-parent crosses to the development of single cross hybrids. This transition brought about several positive changes and notable achievements. It not only contributed to the generation of crucial scientific insights but also led to the production of commercial maize products that aligned with the evolving agricultural paradigms.

From the year 2001 onwards to the present day, the Directorate of Maize Research has successfully developed and introduced nine highly productive QPM hybrids. These hybrids were specifically designed for widespread cultivation across diverse production ecologies within the country. For comprehensive details about these QPM hybrids, their characteristics, and performance, refer to the compiled information presented in Table 2. This strategic shift in maize breeding practices underscores a commitment to advancing agricultural productivity and aligning with contemporary agricultural dynamics.

**Table No. 2** protein and tryptophan content in QPM hybrids

| Hybrid variety | Protein (%) | Tryptophan (%) |
|---|---|---|
| **HQPM 1** | 10.09 | 0.79 |
| **HQPM 4** | 10.31 | 0.67 |
| **Shaktiman-1** | 10.65 | 0.70 |
| **Shaktiman-2** | 10.29 | 0.71 |

## Uses of QPM

As previously discussed, maize has garnered a reputation as an affordable staple, particularly for individuals with limited resources, owing to its nutritional attributes. Quality Protein Maize (QPM) represents a bio fortified; non-transgenic food source that brings forth enhanced protein quality for consumers. Despite its resemblance in appearance and taste to regular maize, QPM distinguishes itself by harboring a naturally-occurring mutant maize gene. This genetic modification amplifies the levels of two crucial amino acids, namely lysine and tryptophan, essential for human protein synthesis. While the overall protein quantity in QPM may not experience a significant increase, the focus lies in augmenting protein quality. This enhancement ensures a greater nutritional benefit when consumed by monogastric beings, such as humans. The versatility of QPM extends to various applications in food and nutritional security, serving as an ideal option for infant food, health food/mixes, convenience foods, specialty foods, and emergency rations. Furthermore, its utility extends to meeting the protein requirements of diverse societal segments, including infants, lactating mothers, convalescent patients, individuals affected by malnutrition conditions like Kwashiorkor, elderly persons, and those who are infirm, among others.

The nutritious attributes of QPM aren't limited to its grain; even its green cob is recognized for its nutritional richness, appealing taste, and widespread consumer preference. Hence, replacing common maize with QPM emerges as a highly effective and attractive measure to address the need for quality protein and elevate the overall human nutritional status. This transformative approach of converting a staple food like maize into a more nutritious variant aligns with sustainable strategies to enhance public health.

The geographical reach of QPM is noteworthy, particularly in remote areas grappling with high malnutrition rates. By delivering a nutritional bonus, QPM seeds can contribute significantly to improving the nutritional well-being of populations. Moreover, studies have underscored the resilience of QPM protein fractions to traditional processing and cooking techniques. In a country like India, where protein malnutrition is prevalent among a substantial population, QPM serves as a valuable solution. The rising prices of meat, eggs, milk, and their products have rendered them unaffordable for many, especially those facing economic challenges globally.

The high biological value of QPM holds the potential to alleviate food and feed costs, addressing the issue of malnutrition among humans while benefiting poultry, livestock, pigs, fish, and other livestock. Maize's integral role in animal feed both within and outside India has prompted studies replacing normal maize with QPM in animal feed. The results have been remarkable, with significant improvements observed in broilers, chickens, pigs, and other livestock. Feed trials consistently demonstrate that pigs fed with QPM exhibit accelerated growth compared to those fed with commercial maize.

Nutritional studies with pigs and chickens further validate the improved performance when QPM replaces normal maize without the need for additional protein supplements. In broiler diets, substituting QPM for normal maize at a rate of 60% significantly reduces the dependency on soybean meal, thereby lowering costs. Similar trends are observed in experiments with finisher pigs, where less soybean meal is required for optimal performance in diets based on QPM compared to those with normal maize. Even beef steers fed on high lysine maize showcase faster weight gain compared to those fed on regular maize.

The nutritional products derived from QPM not only have the potential to substitute expensive industrial foods but can also be prepared in villages and small towns, emerging as a source of rural entrepreneurship. This multifaceted impact underscores the transformative potential of QPM in addressing nutritional challenges, not just for humans but also for the broader spectrum of livestock, contributing to a more sustainable and nourished future.

## Production Technology of QPM

Quality Protein Maize (QPM) demonstrates successful cultivation feasibility in both kharif and Rabi seasons, presenting a versatile option for farmers. It is advisable, however, to cultivate QPM at a considerable distance, approximately 500 meters away from normal or conventional maize fields to prevent unwanted cross-pollination. Optimal sowing times vary, with the ideal window for kharif being June 15 to July 15 and for Rabi from October 15 to November 15. Adjustments in the kharif sowing schedule are recommended to maximize the utilization of natural precipitation.

In irrigated regions, it is advantageous to complete sowing at least two weeks before the onset of rains, a practice that has demonstrated higher yields compared to fields sown either with or without the commencement of rains. In rainfed areas, the key consideration is to sow the crop promptly once sufficient soil moisture accumulates, ensuring robust germination and the establishment of a well-distributed plant stand.

Agronomically, the requirements for cultivating QPM mirror those of traditional maize, encompassing comparable measures for plant protection and weed control. The harvesting and shelling processes align with established practices for normal maize hybrids. This adaptable cultivation approach for QPM not only provides flexibility across seasons but also underscores the importance of strategic timing, spacing considerations, and adherence to best practices for optimal yields. As a result, the integration of QPM into agricultural practices can contribute not only to enhanced nutritional outcomes but also to the overall efficiency and sustainability of maize cultivation.

## Choice of cultivars

In the preceding decade, substantial strides have been made in the development and introduction of maize hybrids, with the emergence of a noteworthy assortment. This includes the unveiling of a single early maturing hybrid, along with the introduction of an impressive array of eight late maturing hybrids, all strategically crafted for widespread cultivation across diverse production ecologies throughout the country, as delineated in Table 2.

Among these hybrids, Vivek QPM9 stands out as a noteworthy representative of the early maturing category, exhibiting suitability specifically for kharif cultivation. Meanwhile, the remaining hybrids within this distinguished collection are tailor-made to thrive in the irrigated belt, demonstrating adaptability for both kharif and rabi seasons. This strategic diversification in hybrid offerings underscores a comprehensive approach to cater to varying climatic and ecological conditions, ensuring that the benefits of these hybrids can be harnessed across different agricultural landscapes.

The deliberate focus on both early and late maturing hybrids not only broadens the temporal window for cultivation but also underscores a commitment to addressing the specific needs of diverse farming contexts. This nuanced approach aligns with the dynamic nature of agricultural practices and seeks to provide farmers with a versatile portfolio of hybrids, enhancing their ability to optimize yields and meet regional agricultural demands effectively.

## Soil and seedbed preparation for QPM

Quality Protein Maize (QPM) exhibits remarkable adaptability, showcasing the potential for cultivation across a diverse spectrum of soil types, ranging from sandy to heavy clay compositions. However, a preference is often accorded to deep and heavy soils, primarily due to their superior water-holding capacity, which contributes to the overall well-being of the crop. It is advisable to steer clear of saline and alkaline soils, given the susceptibility of the maize crop to adverse effects post-germination in such conditions.

Site selection plays a pivotal role in optimizing the growth of QPM, and considerations should be made to avoid low-lying areas and fields with inadequate drainage facilities. The ideal groundwork for cultivation involves the preparation of a clean, smooth, and deeply ploughed seedbed that offers firmness for optimal germination and plant establishment.

For Kharif season cultivation, a strategic approach involves sowing the crop on ridges. This not only mitigates the risk of damage caused by excess soil moisture but also ensures that the root zone receives adequate moisture, fostering a conducive environment for robust plant development. Conversely, during the rabi season, the planting of QPM is recommended on a flat surface. By incorporating these nuanced considerations into the cultivation practices, farmers can harness the full potential of QPM, leveraging its adaptability to varied soil conditions and optimizing yield outcomes in different seasonal contexts. This comprehensive approach reflects a commitment to sustainable and adaptable agricultural practices, aligning with the dynamic requirements of diverse farming landscapes.

## Fertilizer management for QPM production

The precise fertilizer requirements for different fields are contingent upon several factors, including the current fertility status of the soil, the cropping history of the land, and the specific duration of the maize variety being cultivated. It is imperative, prior to sowing, to integrate an ample quantity of Farm Yard Manure (FYM) into the field, thereby enriching the soil with essential organic matter. For an optimal nutrient balance, it is advisable to implement a judicious application of fertilizers. Depending on the maturity profile of the maize variety in question, a balanced approach involves the application of 60 to 120 kilograms of nitrogen (N), 40 to 60 kilograms of phosphorous pentoxide ($P_2O_5$), and 40 kilograms of potassium oxide ($K_2O$) per hectare. This recommended dosage serves as a guideline, allowing for necessary adjustments based on the specific needs identified through soil fertility assessments and the historical cultivation patterns of the field. By adopting a tailored fertilizer strategy, farmers can enhance the overall nutrient content of the soil, promote healthy plant growth, and contribute to sustainable agricultural practices. This meticulous approach aligns with the principles of precision agriculture, acknowledging the variability in soil conditions and crop requirements across different agricultural landscapes.

## Suitable seed rate and plant population

Approximately 20 kilograms of seeds are requisite for the cultivation of one hectare, ensuring optimal sowing density and robust seedling growth. To facilitate the emergence of vigorous seedlings, it is recommended to sow the seeds at a depth of approximately 5 centimetres. Achieving an ideal plant population is crucial for maximizing grain yield, particularly during the kharif season. For this purpose, a target plant density of 65,000 to 70,000 plants per hectare at harvest is deemed necessary. In the rabi season, there is flexibility to enhance the plant population, allowing for an increased density of up to 90,000 plants per hectare.

To attain the desired plant density, it is advisable to adhere to specific row-to-row and plant-to-plant spacing configurations. Optimal results can be achieved by implementing a spacing arrangement of 75 centimetres between rows and 20 centimeters between individual plants. Alternatively, a slightly narrower configuration of 60 centimeters between rows and 20 centimeters between plants can also be employed, ensuring a well-distributed and thriving maize crop. This meticulous attention to planting density contributes to uniform crop development, efficient resource utilization, and ultimately, higher crop yields.

**Irrigation management**

Quality Protein Maize (QPM) exhibits adaptability to rainfed regions, thriving in areas where the distribution of rainfall is sufficient to maintain optimal soil moisture throughout the crop's life cycle. However, to ensure consistently high yields, leveraging available sources of irrigation becomes imperative. Strategically providing one or two irrigations at critical junctures of the crop's growth, particularly during flowering and grain-filling stages, proves crucial for mitigating moisture stress, a vulnerability that maize is particularly susceptible to across all stages of its developmental cycle.

In regions experiencing the rabi season, the cultivation of QPM demands a more intensive irrigation regimen. To attain maximum yields, an estimated 5 to 8 irrigation cycles are recommended during the rabi season. This meticulous irrigation management not only addresses the crop's moisture requirements but also contributes significantly to the crop's overall health and resilience, safeguarding against potential yield-limiting factors associated with moisture stress. By implementing a proactive irrigation strategy, farmers can optimize the productivity of Quality Protein Maize, ensuring a robust and sustainable cultivation process.

**Seed production**

The challenge of QPM hybrid seed availability has become a focal point of concern for public institutions, particularly in light of the absence of private entities engaging in QPM research initiatives. Addressing this concern requires a concerted effort to establish robust solutions, with a primary focus on the development of regional seed hubs. These hubs can serve as alternative sites for the production of high-quality QPM hybrid seeds, necessitating careful consideration of factors such as appropriate isolation distances, well-connected road networks, guaranteed irrigation facilities, and adequate storage capabilities.

A proactive approach involves identifying new regions in northern India that offer optimal conditions for seed production, particularly during the rabi season when irrigation facilities are readily available. This expansion of seed production sites not only contributes to overcoming seed availability challenges but also enhances the resilience of the QPM hybrid cultivation process. By strategically establishing these regional seed hubs, the agricultural community can ensure a consistent and reliable supply of QPM hybrid seeds, ultimately fostering the broader adoption of this nutritionally enriched maize variety.

The prospect of seed production in the entire eastern, central, and western regions presents an exceptionally favorable and congenial environment, particularly during the rabi season. Embracing seed production in these regions has the potential to bring high-quality seeds right to the farmers' doorsteps, featuring excellent germination rates. This strategic approach not only curtails the expenses associated with transportation but also ensures timely sowing, consequently leading to enhanced harvest outcomes.

Furthermore, this initiative serves as a catalyst for the widespread dissemination of developed and improved agricultural technologies among farmers. Historical evidence indicates that when seed production is initiated, seed producers readily adopt improved technologies, facilitating their rapid diffusion to other farmers. This cascading effect contributes to the broader adoption of advanced agricultural practices, thereby fostering a culture of innovation and efficiency within the farming community. Overall, the expansion of seed production in these regions not only addresses logistical challenges but also serves as a dynamic platform for knowledge transfer and technology adoption in agriculture.

The Directorate of Maize Research has successfully pinpointed a promising location in West Bengal for seed production, specifically focusing on HQPM-1. This initiative is being implemented at the grassroots level, engaging farmers under the innovative seed village model. The active involvement and support of a dedicated farmer group, Krishi Swambar Gosthi, Kulgachi, Nadia (W.B.), have played a pivotal role in driving this endeavor. Expanding the scope, additional sites in Banswara and Dungarpur districts of Rajasthan have been identified. The Rajasthan State Seed Corporation has taken the lead in collaboration with the National Seed Corporation of India (NSC) and the Directorate of Maize Research. Together, NSC and DMR have conducted comprehensive hybrid seed production training sessions, benefitting hundreds of farmers in these regions.

The hybrid seeds cultivated in these locations are not only distributed to farmers, particularly those belonging to tribal communities, under seed subsidy schemes but are also earmarked for utilization as both food and feed. This comprehensive approach is anticipated to contribute significantly to addressing the challenge of malnutrition prevalent in these areas. Through strategic partnerships and farmer-centric initiatives, the Directorate of Maize Research is actively fostering sustainable solutions for both agricultural and nutritional concerns.

Quality Protein Maize (QPM), being a product of public sector research, holds significant importance in enhancing the food and nutritional security of the nation. To propel and fortify these vital initiatives, it is imperative to provide QPM with a prominent and well-deserved position in state policies. This entails recognizing the distinctive role that QPM plays in contributing to the overall well-being of the population.

Moreover, an immediate and pressing requirement exists to introduce genetically diverse germplasm into QPM research. This diversification strategy aims to enrich the genetic pool, fostering resilience and adaptability in maize varieties. Simultaneously, there is a critical need to focus on the development of high-yielding hybrids that align with international quality parameters. By embracing genetic diversity and advancing hybrid technologies, the nation can not only bolster its agricultural landscape but also meet global standards for nutritional excellence. This multifaceted approach underscores the urgency of integrating QPM into broader agricultural policies for sustained growth and nutritional well-being.

## Conclusion

Quality Protein Maize (QPM) emerges as a transformative solution, addressing not only the nutritional challenges faced by diverse populations but also contributing significantly to sustainable agricultural practices. Its evolution from the opaque-2 gene to the sophisticated QPM hybrids exemplifies the dynamic nature of agricultural research. The comprehensive cultivation guidelines, diverse hybrid offerings, and strategic seed production initiatives discussed underscore the concerted efforts to make QPM a cornerstone of global food and nutritional security. Recognizing the pivotal role of QPM in state policies and prioritizing genetic diversity will further propel its positive impact on health, agriculture, and socio-economic well-being.