CORN OIL: An emerging industrial product

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Preface

Maize is an abundant food and feed crop. Diversied use of crop adds higher value to its cultivation and production. Maize is one such crop which yields several useful products. Hence it remains one of the favourite crops in industrial sector. Among several corn related products, corn oil is an emerging one. The recent surge of urbanisation, health consiouness and improved life style of masses demands quality products for consumption. Corn oil is becoming popular among edible oils owing to its unique health related benefits. Corn oil extraction also opens up new avenues of enterprenuership to corn growers and processsors. This booklet provides technical as well as scientific information for harnessing the oil value of corn.

Authors

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INTRODUCTION

Corn is one of the most successful food, feed and industrial cereal. Industries consume 12-15% of corn production in India. Corn flour, corn oil, cornflake, corn syrup, popcorn, rice corn and corn soap are some popular corn products. Corn oil is a pale yellow oil procured from the kernel of corn. The first commercial production of corn oil took place in 1889. Refined corn oil is tasteless and odorless oil. Corn oil is used as a cooking medium and for manufacturing hydrogenated oil.

a

b

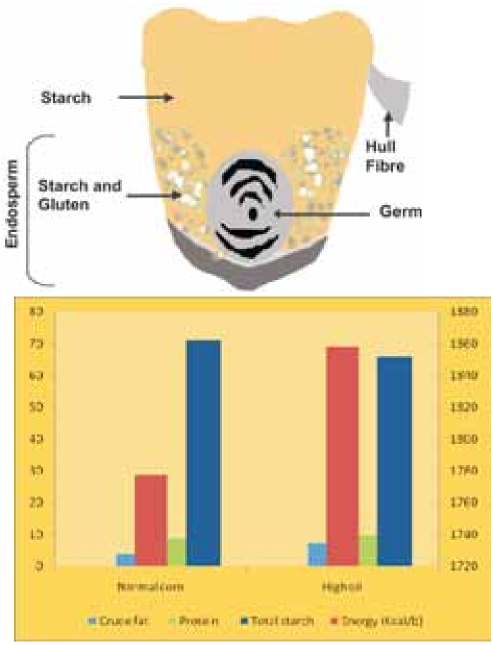

Figure 1. a. Parts of corn kernel, b. Nutrient composition of corn kernels

Corn having oil content of more than 6% is called high oil corn. The parts of corn seed/kernel are endosperm (82%), germ (embryo and scutellum) (12%) (Figure 1 a & b). 80 to 84% of total kernel oil is present in the germ region followed by 12% in aleurone and 5% in endosperm.

Corn Oil Value

Among the grain crops, the oil is highest in oats (Figure 2). Unsaturated fats are found in products derived from plant sources, such as vegetable oils, nuts, and seeds. There are two main fatty acids: polyunsaturated (PUFA) (high concentrations in sunflower, corn, and soybean oils) and monounsaturated fatty acid (MUFA) (high concentrations in canola, peanut, and olive oils). The high PUFA content meets the essential fatty acid requirements in human nutrition. In corn oil, the total percentage of PUFA constituted by linoleic acid (18:2) alone is about 60%

Good cooking oil

1. Canola oil
2. Flax seed oil
3. Groundnut oil
4. Olive oil
5. Non-hydrogenated soft margarine
6. Safflower oil
7. Sunflower oil
8. Corn oil

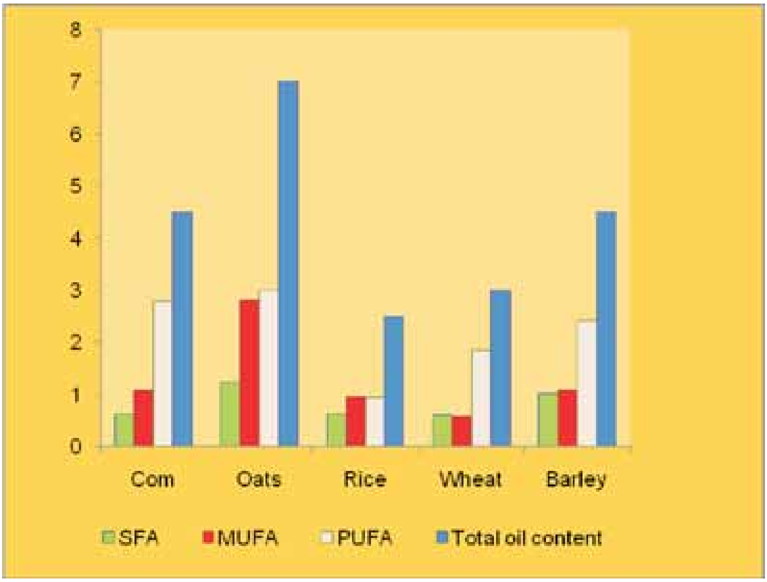

Figure 2. Percentage distribution of total oil, PUFA, MUFA and SFA content in cereals (Dunford, 2005)

and MUFA (oleic acid; 18:1) is about 24%. Among saturated fatty acids (SFA), palmitic acid (16:0) is almost 13% and stearic acid (18:0) is 1%. The percentage of PUFA is high in corn among cereals (Figure 2). Figure 3 shows the percentage of fatty acids in common edible oils in total fat percent. SFA is highest in palm kernel and coconut oil. Corn oil ranks fourth in PUFA content. Olive and canola oil are highest for MUFA.

Corn oil is a rich source of linoleic acid (essential fatty acid), which is one of two essential acids necessary for the integrity of the skin, cell membranes and the immune system and for synthesis of eicosanoids necessary for reproductive, cardiovascular, renal, gastrointestinal functions and resistance to disease and it is highly effective for lowering serum cholesterol, primarily low-density-lipoprotein cholesterol. Omega-6 fatty acid is rich in corn, safflower, sunflower, soybean, and cottonseed oil. Oil has good stability in cooking and storage because of low proportion of linolenic acid, a fatty acid prone to oxidation.

Utilisation of high oil corn in livestock feed increases energy density, allows a higher gain: feed consumption ratio, improves amino acid balance and reduces the need for expensive dietary supplements. High oil corn has higher total protein containing higher levels of essential amino acids like lysine, threonine and methionine. High oil corn is better in all nutrients except starch content of normal corn. High oil corn has larger embryo where amino acids are well balanced. It is also recognized as an excellent source of antioxidants (tocopherol) and Vitamin E. Antioxidants are important health wise and helps retards oil rancidity. Corn oil contains 968 milligrams of phytosterols per 100 gram of oil. It has one of the highest phytosterol levels among the refined vegetable oils. Phytosterols reduce blood cholesterol by inhibiting its absorption from the intestines. Corn oil is the only product containing a natural mixture of free phytosterol, phytosterol esters and phytostanol esters. Table 1 summarises the features of important edible oils including corn oil.

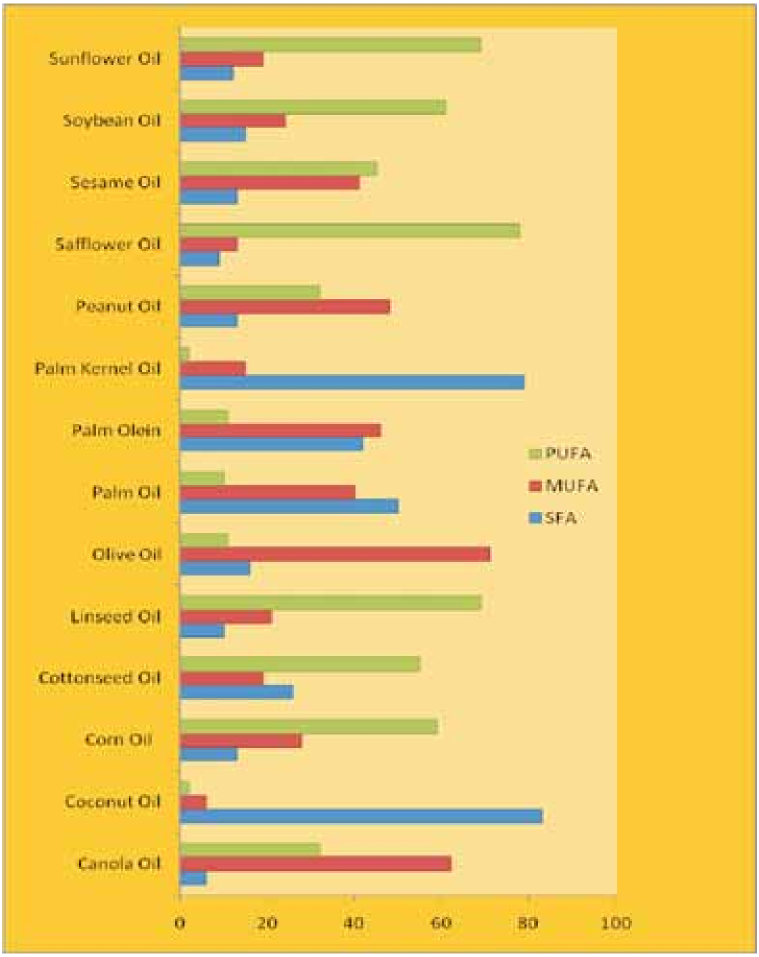

Figure 3. Percentage of fatty acids in edible oils in total percent of fat

Table 1. Summary of features of important edible oils

		Corn Oil	Canola	Sunflower	Olive	Safflower	Soyabean	Rice Bran	Mustard Oil
Total oil content		3-4 %	43 %	45%	30%	30-40%	20%	3%	34%
Temperature		Medium Temp. 457°F (High)	450°F (medium temperature) Not to be used at high temperature	High 475°F	375-468°F (depending on the type) Not to be used at high temp	High 509°F	High 440°F	490°F (High)	489 °F
Vitamins/ Minerals (*ppm. stands for parts per million)		Omega-6 & 3, Vitamin C, Highest amount of antioxidants among all oils	Vitamin A,D,E,K; Omega-3, beta-carotene	Vitamin E (highest), Omega-6	Antioxidants	Vitamin E, Omega-6Cis-linoleic	Omega-3Vitamin E	Vitamin E, Squalence, Neutraceuti-cal, Gamma-oryzanol	Antioxidants Essential Vitamins
Fats	MUFA / Oleic	25%	61%	20%	77%	13%	24%	47%	60%

	PUFA / Linoleicacid	**62%**	33%	69%	9%	77%	61%	33%	21%
	Saturated fats	**13%**	7%	11%	14%	10%	15%	20%	13%
SFA: MUFA: PUFA		**13: 25: 62 (High PUFA)**	6: 62: 32 (Lowest SFA)	9: 82: 9 (high oleic),9: 65: 26 (regular)11: 20: 69 (linoleic)	14:77:8, 1- Omega-3 (Highest MUFA)	9: 13: 78 (High PUFA)	15: 24: 58, 3-Omega-3	22:43:35 (High MUFA)	3:65:25,7- Omega-3
Digestibility		**High**	Slows digestion	Improves apparent digestibility of SFA, MUFA and PUFA but reduces the retention of MUFA and PUFA	Good even at high temperature	Good	Low Digestibility	Easily digested	Stimulates digestion

Colour	**Golden Yellow Reddish shade**	Light yellow	Pale Transparent Yellow	Yellowish to green (Greener it is, purer it is)	Pale Yellow	Clear, transparent, water like colourLight Yellow	Light golden colour	Yellow
Taste/ Aroma	**Tasteless**	Mild flavour	Yes (High Oleic),No (Regular)	Strong flavour	No flavour Odourless	No/Bold tasteBland (Non Spiced) Medium Odour	Pleasant nutty & buttery taste	Pungent tasteSpicy odour
Viscosity / Oil density	**Low viscosity**	Slightly thicker in viscosity	Low viscosity			Slightly thicker in viscosity	Light viscosity making it non-sticky and easily emulsifies in dressings and sauces	
Uses	**Frying, baking, salad**	Frying, baking, salad dressing	Cooking, salad dressings,	Sautee, stir frying, cooking,	Cooking, salad	Cooking, salad dressings, vegetable	Cooking, frying, deep frying,	Cooking, frying, deep frying,

	dressings, margarine, shortening		margarine, shortening	salad oils, margarine	dressings, margarine	oil, margarine,	salads, dressings. Very clean flavoured & palatable.	salads, dressings. Very clean flavoured & palatable
Benefits	**1. Easy to Digest 2. Benefi-cial to health heart 3. Reduce risk of Chronic diseases**	1. Lower risk of heart disease 2. Lower rates of cancer	1. Lower the level of bad cholesterol without lowering level of good cholesterol	1. Reduce heart disease, risk of some cancer, diabetes2. Influence body fat distribution	1. Helps in losing weight 2. Reduce level of cholesterol 3. Strength-en immunity 4. Helps in treatment of diabetes 5. Promotes hair growth and a healthy skin	1. Reduce cancer cell activity 2. Lower cholesterol 3. Helps in controlling osteoporosis 4. Control blood sugar level 5. Cheap	1. No cholesterol & No trans fatty acids. Naturally low in saturated fat. 2. Rich in oleic and linoleic fatty acids. 3. Naturally free of trans fatty acids (TFA's)	1. It can be used as antibacterial oil 2. Protects teeth from germs if rubbed on gums and make gums strong 3. Organic mustard oil helps preventing cancer and is also helpful for slowing down the

								ageing process
Additional	**Recommend-ed by American Health Commission (AHC) 2. Retains 100% food taste**	Approved as healthiest oil by many associations (American Diabetic Association, and American Heart Association)	Retain moisture in skin & resist infection in infants	1. Longer storage life2. Healthiest when consumed uncooked.	In salad because doesn't get solidify when chilled, used in both	Soybean oil contains natural antioxidants which remain in the oil even after	Recommended by The American Heart Association	Helps in winter for making body warm and generating mild irritating effect through massage on bodyIt can be used as an irritant for stimulating sensation in senseless organs and muscles. Irritants are also useful for driving up muscles

CORN OIL IN EDIBLE OIL INDUSTRY

India is a leading player in edible oils, being the world's largest importer and the world's third-largest consumer. The primary sources of oil are soybeans, rapeseed, sunflower, groundnut, cottonseed, coconut, palm and olive. In terms of volumes, palm oil, soybean oil and mustard oil are the three largest consumed edible oils in India (Figure 4). Among the non-conventional oils, rice bran oil and cotton seed oil are the most important. The corn oil emerged in USA. The large scale production of the corn oil began in the 1910s. Since 1950s, developed countries have taken up corn oil. Presently, corn oil makes a meagre proportion in the edible oil consumption. Corn oil is used in margarine, soup, soap, paint, as rust preventative and many more products.

In India, most of the corn is used for feed industry and starch extraction. Germ used to be a waste product obtained after starch extraction from seed. Currently, germ is in demand because of its high oil content and utilisation as byproduct. Refined corn oil is considered to be the best edible oil used internationally. Considering the large planting area under corn and high unit production there is present commercial interest in corn oil production. Cost benefit ratio in maize is highest due to its high productivity. Through good cultivars, processing and comprehensive utilization, the value of high-oil corn can be improved considerably.

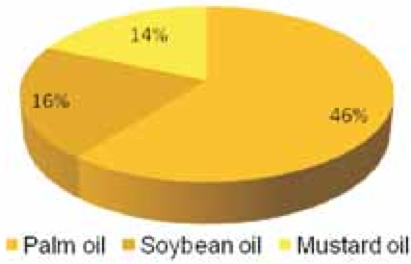

Figure 4. Percentage share of edible oil consumption in India

(Source: www.icra.in)

Corn Oil Extraction

The oil is typically extracted from the germ by a combination of mechanical expression and hexane extraction. During starch extraction process the germ is seperated from kernel after cleaning and steeping. The oil is seperated from germ through steps given in Figure 5. Refining involves several steps: (i) formation of sodium soaps of the free fatty acids, (ii) removal of the emulsion containing the soaps and phospholipids by centrifugation, (iii) removal of waxes by chilling, (iv) removal of pigments by contact with bleaching clays, (iv) removal of odours by high-vacuum distillation at 225°C to 260°C. The fatty acid fraction is recovered by heating the emulsion in the presence of sulphuric acid and is sold as an ingredient for use in feed rations. The germ residue is saved and used as a component of animal feeds. The starch component of the grain is further processed to give a number of products. The wet corn milling operation recovers 50-60% of germ oil. With right oil extraction machinery, a number of useful products such as corn oil and corn meals can be extracted.

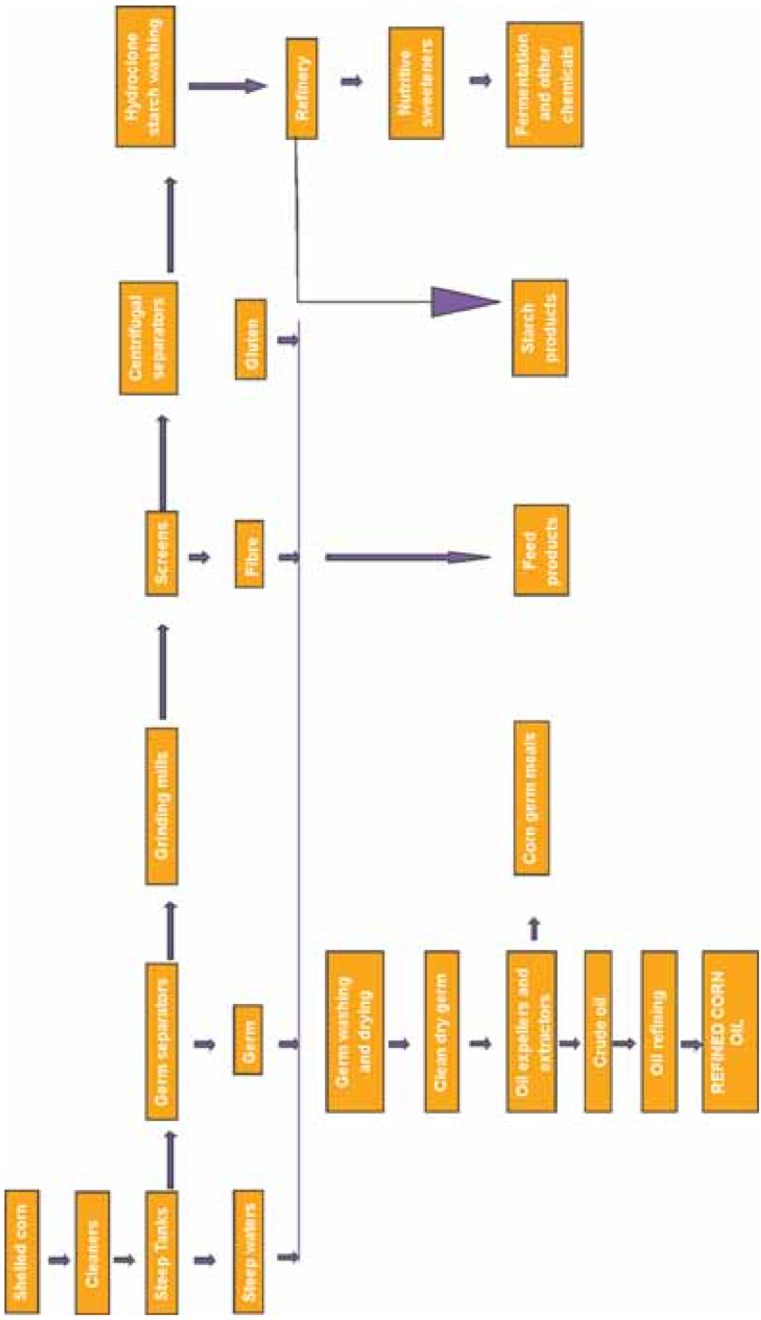

Figure 5. Schematic diagram of corn oil extraction

PRODUCTION TECHNOLOGY

Production technology of high-oil corn is same as normal corn.

Seasons	*Kharif, rabi* and *zaid*
Land Selection	From hilly regions up to an elevation of 2700m
	All types of soils from sandy to heavy clay
	5-6 irrigations
	Avoid water stress at the time of anthesis
Land Preparation	Disc ploughing followed by land levelling
	FYM @5-6 tonnes/ha during last ploughing.
	Inter row distance of 60-75cm; Intra row spacing 15-30cm
Date of Sowing	10-15 days before onset of rain in irrigated areas
	Best planting time is June-July in *kharif* (rainy) and September-October in *rabi* (winter) season
Seed Rate	10-11 Kg seeds ha^{-1}
	Plant population for optimum yield is 55000-60000 plants per hectare
Method of Sowing	Two seeds per hill are dibbled manually or mechanically one third from the top on the side of the ridge.
	Planting dept - 3-4 cm
	Plants are thinned to one plant per hill 10-12 days after emergence

Nutrient Management	110-130 Kg of nitrogen, 60-80 Kg of phosphate (P_2O_5) and 55-65 Kg potash (K_2O) ha^{-1}
	Fertilizer should be applied in 1 or 2 bands approximately 7-8 cm to the side and 5-7 cm below the seed.
Weed Management	Weed-free during the early stages of plant growth
	Efficient weed control is achieved for 30-35 days through a spray of the herbicide Atrazine @ 1 Kg ai/ha for 1-2 days after initial irrigation
Water Management	4-5 irrigations in heavy soils and 7-8 irrigations in light soils
	Irrigate at least 2.5-4.0 cm a week in order to obtain high yield
	Critical time periods are tasselling and silking
Intercultivation	Top dressing of Urea is done 25 days after emergence after running a cultivator in between the rows that will help weed control and better root aeration apart from soil water conservation
Pest and Disease Management	Endosulfan 35EC @ 2ml/l of water is given to 10-14 days old plants to take care of stalk borers *Chilo partellus* in *kharif* and *Sesamia inferens* in *rabi*
	Crop rotation and sequential planting
	Spray with Bavistin @ 1 g/litre takes care of most of the foliar diseases

XENIA EFFECT AND HIGH OIL CORN PRODUCTION

Pollen parent also influences the oil content of the seed parent called as xenia effect. Male gametophyte of the high oil population has additive or dominant gene action causing the germ size of the normal oil hybrid to increase slightly and increase the concentration of oil in the germ with small change in grain yield.

Recently, there has been much interest in producing high-oil corn from hybrids using the topcross system. The system involves planting two types of corn. One type, representing 90 to 92% of the seed, is an elite hybrid taken as the "grain parent." remaining is elite high oil inbred as "pollinator." The grain parent is an elite commercial hybrid detasselled during pollination. The pollen shed from these pollinator plants contain genes that cause a kernel to produce a much larger than average germ or embryo utilising xenia effect). As most of the oil and essential amino acids are in the germ, the oil and protein quality of the grain produced by fertilization with these pollinators is enhanced. Pollinator plants contribute very little to overall grain yield.

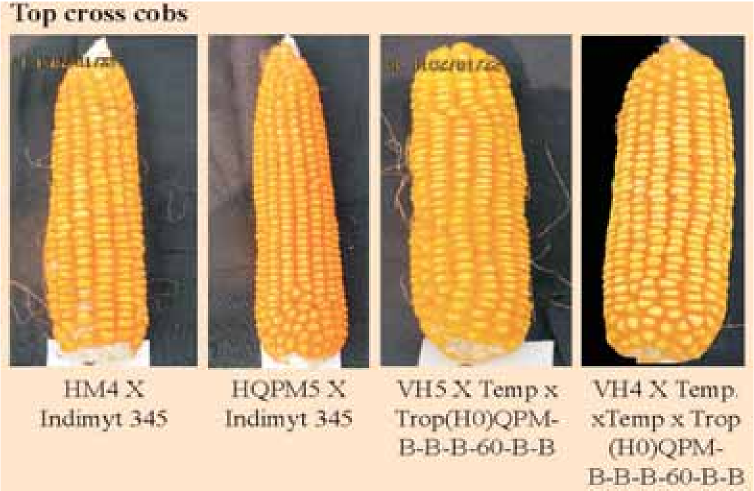

Figure 6. Mature corn cobs of top cross hybrids of high oil lines

Thomison *et al*. (2002) used this system to produce high oil grain and designated it as TC Blend®. High oil trait would not be expressed if pollen from normal or low oil corn hybrids pollinates male sterile hybrids in the blend. In our experiments also topcrosses were found to be better in terms of seed setting and seed production compared to single crosses (Figure 6).

HIGH OIL CORN IMPROVEMENT

To increase the oil content, efficient corn breeding programs has to be developed, which requires the knowledge of inheritance of oil related traits.

A high-oil corn hybrid is the result of long term conventional selection and breeding for the trait. The first high-oil corn varieties were selected in 1896 at the University of Illinois. High oil inbreds show high rate of oil accumulation from 15-45 days after pollination as compared to normal inbreds. Germ weight and kernel weight increased linearly until the seventh week of kernel development. The third and fourth week of kernel development is the time of rapid metabolism in producing oil. It reaches maximum by 45 to 48 days after pollination. Oil production is completed when seed is physiologically fully mature. Increased kernel oil concentration has been attributed to increased embryo: kernel ratio and increased embryo oil concentration. Oil content seems to be less influenced by the effects of environment and genotype x environment interaction. The additive genetic variance seems to be the main component in the control of this trait. Most literature illustrates influence of the male parent genotype through xenia effect in the determination of oil content in corn kernels. Corn fatty acid composition is variable and heritable. In India under National Agricultural Technology Project two high oil populations, HOP-I and HOP-II have been developed with seven per cent oil content. Sowing these two populations in 6:1 ratio with promising hybrids improves oil content without compromising yield. Hybrids are detassled at flowering. At Directorate of Maize Research, New Delhi, corn inbreds exhibited high variability for oil content, which varied from 7.37 % in Temp x Trop (HO) QPM-B-B-B-60-B-B to 2.86 % in EC646025. The best high oil corn inbreds found were Temp x Trop(HO)QPM-B-B-B-60-B-B, Temp x Trop (HO)QPM-B-B-B-100-B-B, DMHOC4, HKI Talar, Temp x Trop (HO)QPM-B-B-B-57-B-B, HKITall-8-1-1 and AF-04-B-5796-A-7-1-1 (Figure 7). These inbreds can be used

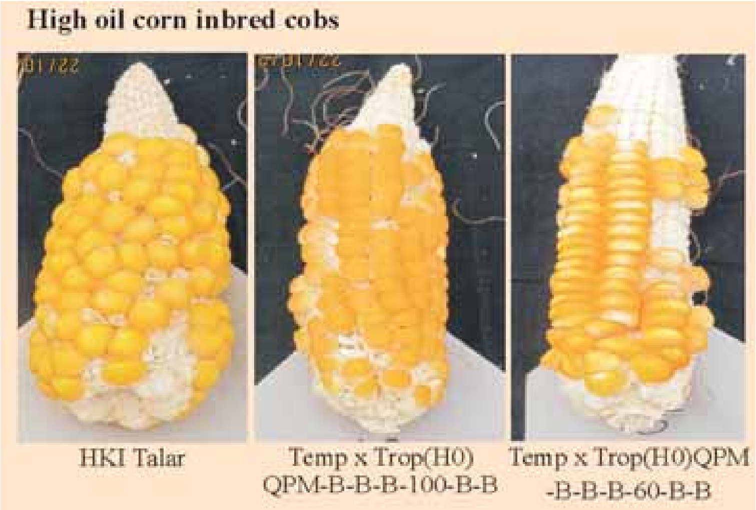

Figure 7. Mature corn cobs of high oil lines

in further breeding programme for developing hybrids with high oil content. NIRA (Near Infra red analyser) and NIRS (Near Infra red Spectrophotometer) are non-destructive laboratory instruments to estimate oil content in a given sample of seeds in lot or singly on dry weight basis. Soxhlet apparatus is for destructive oil estimation method

Generally, high oil hybrids have high oil kernels but with reduced starch levels, smaller endosperm and kernel size. Such seeds have shorter longevity and greater deterioration. Synthesis of oil is physiologically independent in the interval from 4 to 7% oil. The fatty acid composition of corn oil is affected by position of kernels on the ear. Palmitic and linoleic acid content of the oil increases for kernels from the base to the tip of the ear. On the other hand, oleic fatty acid content of the kernels decreases from base to tip. Sampling of kernels in the central portion of the ear is recommended for samples to be analyzed for fatty acid composition. With each one per cent oil increase, starch in kernel would decrease by 1.48% to 1.83%. The average grain yield of the high oil hybrids is reduced by 5% compared to normal hybrids. Grain yield of high oil hybrids reduces as oil increases greater than eight per cent.

PROSPECTS, STRATEGIES AND GOALS

The spotlight towards quality food products has initiated research and development activities to develop and promote healthy food. Quality products are becoming increasingly important in agriculture. Corn oil is gaining importance due to its health benefits. Subsequently, non-traditional oils such as corn oil are entering market. Development of high oil corn has picked up recently in India.

Conventional selection breeding can increase oil in kernel. Selection for high oil increases the proportion of germ and further content of germ oil. The problems that overshadow successful production of high oil corn are low grain yield potential, physiological cost of oil synthesis, low seed vigour, low kernel weight, shorter seed longevity and poor germination of high oil corn lines. Study of seed related traits at advanced level on seed germinability, setting, maturation and mobilisation of oleosomes and oleosins can be done to overcome these demerits. The amenable proportion of embryo and endosperm in oily kernel can increase nutrients present especially in embryo without reducing starch in endosperm. A breeding program to increase oil content in the kernels should be considered to avoid grain yield reduction by accumulating positive alleles distributed among genotypes. Gathering of positive alleles from different genotypes can provide transgressive segregants with higher oil content.

Corn oil is an important value added product from left over embryo/germ in addition to starch extraction from endosperm of kernel. The commercial and economic value of discarded embryo is enhanced when corn oil is extracted from it. Increasing the proportion of germ and oil content in germ will be the foremost objective of breeding for oil in corn. Exploitation of xenia effect is a well established fact for breeding of oil in corn. It imparts increased oil in germ as well as germ size without affecting yield. The pollinators need to be high in oil with good amount of pollen and increased duration of pollen shedding. Hence, prospecting germplasm for good pollinators is essential. Female line can be good normal corn inbred, or elite single cross hybrid giving good seed production. Elite single cross hybrid can be used as female after detasseling. Higher doses of N, P and K influence grain yield and oil production per hectare.

At present, the availability of molecular tools has widened the knowledge of genetics of oil and oil related traits in corn. QTL analysis has given information of several QTL regions governing quality and quantity of oil. In good quality oil there is increase of oleic acid and reduction of saturated fatty acid *i.e.*, palmitic acid. Metabolism/pathways/enzymes involved in accumulation of oil, starch and protein in kernel can be utilised for studying beneficial correlation between fatty acids, carbon flow for oil, starch and protein synthesis and to improve the value and amount of oil. Abundant information is available describing the synthesis of fatty acid and triglycerol. Regulatory role of over expression of *DGAT* allele in determining seed oil content during seed maturation is well noted. Genetic engineering and '*omics*' approaches can give better understanding of plant metabolism mechanism. Marker assisted selection could allow more efficient breeding program for this trait using QTLs with no or lower pleiotropic effects on grain yield, favourable QTLs from elite and non-elite lines for high oil content identifiable before flowering, marker-assisted backcrossing of QTLs with larger phenotypic variation. Cost-effective marker-assisted selection can be successful in plant breeding programs.

Germ derived from different conventional wet mill process appeared to have a slightly increased amount of oil content relative to the other processes. There is a strong correlation between the market value of germ and its extractable oil content.

Processors carry out blending of oil such as corn oil with olive oil and rice bran oil *etc*. Blending with corn oil results in recommended ideal levels of monounsaturated and polyunsaturated fatty acids. This ensures excellent flavour stability as well as the taste of food. Annexure I gives in detail the Agricultural Produce (Grading and Marking) (AGMARK) specifications regarding corn oil grade and quality for due purposes. Contract production of high oil grain may offer corn growers higher profits through premiums. In this context concept of seed village for production of high oil corn linked with suitable market outlets is to be encouraged with buy back guarantee is to be encouraged. An assured market of high oil corn is to be created so that farmers receive good premium of their produce. Higher corn oil content is a desirable trait for corn starch industries, especially starch. It is observed that majority of the corn based starch factories are located in the states of Gujarat, Maharashtra, Andhra Pradesh, Karnataka, Haryana and Punjab (Figure 8). Eastern India states like Bihar and Uttar Pradesh lacks such factories.

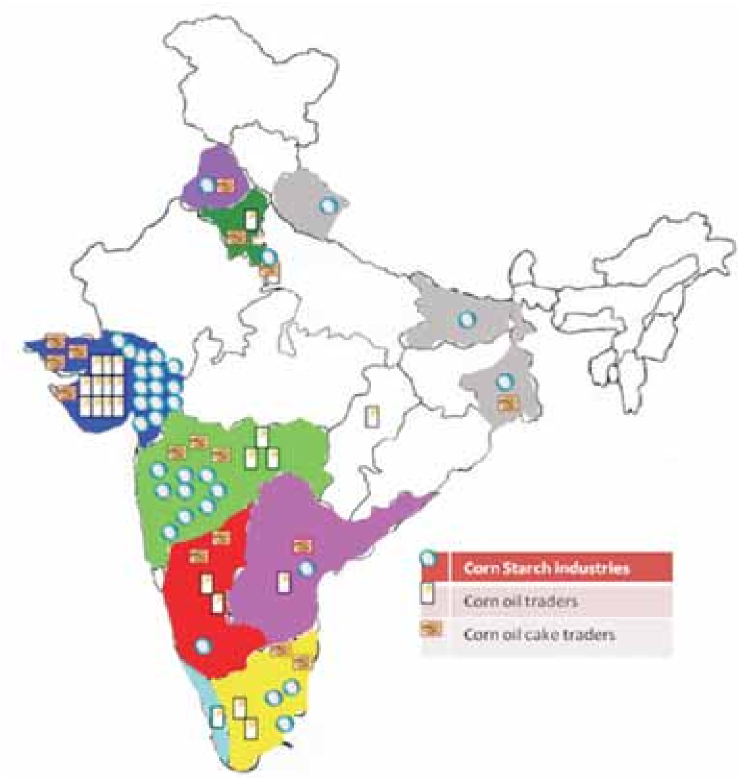

Figure 8. Relative distribution of corn starch, oil and oil cake traders in India

Tapping these corn producing areas for corn based industries especially for starch can supplement corn oil industry. Extraction of corn oil is a latest area of entrepreneurship. In the coming years, emphasis will be to support corn oil to catch a formidable position in edible oil market. High oil is a useful, unique and specialty trait for plant breeders.

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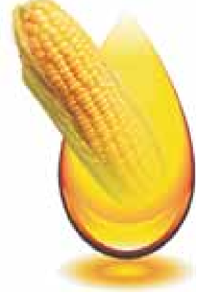
Annexure I

Agmark grade designation and definition of quality for Maize (Corn) Oil

1	**Grade Designation**	**Refined**
2	Moisture and impurities percent by weight (not more than)	0.10
3	Colour on Lovibond scale* in 1/2" cell expressed as Y + 5R (not deeper than)	10
4	Specific gravity at $30^0/30^0$C	0.913 to 0.920
5	Refractive Index at 40^0C	1.4645 to 1.4675
6	Saponification value	187 to 195
7	Iodine value (Wij's method)	103 to 128
8	Unsaponifiable matter percent by weight (not more than)	1.5
9	Acid value (not more than)	0.5
10	Description	Maize (corn) oil shall be obtained by a process of expression from the germs of clean and sound seeds of the plant *Zea mays* Linn. fam. Gramineae which are separated from the remainder of the kernel by the wet or dry milling process in the manufacture of starch or glucose. The oil shall be refined by neutralization

		with bleaching earth and/ or activated carbon and deionised with steam. No other chemical agent shall be used.
11	General Requirements	The oil shall be clear and free from turbidity when a filtered sample of oil is kept at 30^0C for 24 hours. The oil shall be free from rancidity, adulterants, sediments, suspended and foreign matters, other oils and substances, mineral oil, separated water and added colour and flavouring substance and obnoxious odour. The oil may contain permitted anti-oxidants not exceding in concentration as specified under Prevention of Food Adulteration Rules 1955.

NOTE : *In the absence of Lovibond Tintometer, the colour of the oil shall be matched against standard colour comparators.



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