THE WHEAT CROP

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WHEAT

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Introduction

Wheat (*Triticum aestivum L*) is the most extensively grown cereal crop in the world, covering about 237 million hectares annually, accounting for a total of 420 million tonnes (Isitor *et al*., 1990; Langer and Hill, 1991; Olabanji *et al*., 2004), and for at least one-fifth of man's calorie intake (Ohiagu *et al*., 1987).

Wheat is an annual grass growing to between ½ to 1 ¼ meters in height, with a long stalk that terminates in a tightly formed cluster of plump kernels enclosed by a beard of bristly spikes (Smith, 2010). It is grown all over the world for its highly nutritious and useful grain, as one of the top three most produced crops, along with corn and rice (see Table 1 for production figures). It is used in the production of bread, biscuits, feeds, confectionary, amongst many, utilization.

The crop, which has been cultivated for over 10,000 years probably, originates in the Fertile Crescent, along with other staple crops. However, ancestral wheat may have looked very different from what we presently have today, with much smaller kernels. Early domesticators of wheat obviously wanted to select for plants with particularly large kernels, since more nutrient could be eked out from each stalk.

Wheat has been cultivated in Nigeria for centuries (Olugbemi *et al*., 1979; Ohiagu *et al*., 1987). Ample evidence exists to show that wheat has been cultivated in Nigeria as early as 200BC, although the currently cultivated varieties are relatively recent introduction (Olabanji *et al*., 2004). However, Nigeria's domestic wheat production has remained at a very low level in spite of the ever – rising demand for the crop. The constraints to the cultivation of wheat in most wheat growing areas in Nigeria include climatic requirements, appropriate agronomic practices and preference for the cultivation of vegetables (Ohiagu *et al*., 1987). Development of improved agronomic practices in respect of land preparation, planting, nutrition, water management, crop protection, harvest and post harvest technology have been the major areas where researchers have concentrated their efforts.

Table 1: International wheat production statistics in million metric tons

Country	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
China	109.9	104.5	96.3	91.6	86.5	90.3	93.9	99.7	113.9	109.7	123.3	110.6
India	74.9	69.4	72.0	72.1	65.1	72.8	69.7	76.4	70.8	65.9	69.4	62.6
United States	53.6	57.3	57.1	58.7	63.8	44.1	53.3	60.8	62.7	69.4	67.5	62.0
Russia	49.4	45.0	47.6	45.4	34.1	50.6	47.0	34.5	31.0	27.0	44.3	34.9
France	33.2	35.4	36.9	39.7	30.5	38.9	31.5	37.5	37.2	39.8	33.9	35.9
Pakistan	23.5	21.3	21.6	19.5	19.2	18.2	19.0	21.1	17.9	18.7	16.7	16.9
Germany	21.4	22.4	23.6	25.4	19.3	20.8	22.8	21.6	19.6	20.2	19.8	18.9
Canada	20.6	27.3	25.6	25.9	23.6	16.2	20.6	26.8	26.9	24.1	24.3	29.8
Turkey	17.7	20.0	21.0	21.0	19.0	19.5	19.0	17.5	16.5	18.5	16.2	16.2
Kazakhstan	16.5	13.5	11.1	9.9	11.5	12.7	12.7	9.1	11.2	4.8	8.7	8.0
Iran	15.0	14.5	14.5	14.0	13.4	12.5	9.5	7.0	8.0	11.0	10.2	8.8
Argentina	14.0	14.0	16.0	14.6	14.5	12.3	15.4	16.5	15.7	11.5	14.8	15.9
Ukraine	13.8	14.0	18.7	17.5	6.9	20.6	21.4	10.2	13.6	14.9	18.4	13.5
United Kingdom	13.4	14.7	15.0	15.5	14.3	16.0	11.6	16.8	14.9	15.5	15.1	16.1
Australia	13.0	10.8	25.1	21.9	26.1	10.1	24.3	18.5	24.1	22.1	19.4	23.7
Poland	8.4	7.1	8.6	9.9	7.9	9.3	9.3	8.5	9.1	9.5	8.2	8.6
Egypt	7.4	8.3	8.1	7.2	6.8	6.6	6.3	6.6	6.3	6.0	5.8	5.7
Italy	7.3	7.1	7.5	8.6	6.2	7.6	6.5	6.9	7.3	8.1	6.8	8.3
Spain	6.4	5.6	3.8	7.1	6.3	6.8	5.0	7.3	4.9	5.3	4.6	6.0
Uzbekistan	5.9	6.0	5.8	5.4	5.4	5.0	3.7	3.5	3.6	3.6	3.0	2.7
Denmark	4.5	4.8	4.8	4.8	4.7	4.1	4.7	4.7	4.5	5.0	5.0	4.8
Syria	4.5	4.7	4.7	4.5	4.9	4.8	4.7	2.7	2.6	4.1	3.0	4.1
Brazil	4.0	2.5	5.2	5.7	6.2	3.1	3.4	1.7	2.5	2.3	2.5	3.3
Hungary	4.0	4.4	5.0	6.0	2.9	3.9	5.2	3.7	2.6	4.9	5.3	3.9
Czech Republic	4.0	3.5	4.5	5.0	2.6	3.9	4.5	4.1	4.0	3.8	3.6	3.7
Afghanistan	3.8	3.2	4.3	2.3	3.5	2.7	1.6	1.5	2.5	2.8	2.7	2.3
Ethiopia	3.0	2.8	1.7	1.6	1.4	1.5	1.6	2.5	2.1	1.5	2.0	1.6
Mexico	3.0	3.3	3.0	2.9	2.8	3.2	3.3	3.3	3.1	3.2	3.6	3.4
Romania	2.9	5.5	7.0	7.8	2.5	4.4	7.8	4.4	4.4	5.0	6.6	3.1
Saudi Arabia	2.7	2.4	2.6	2.8	2.5	2.4	2.1	1.8	2.0	1.7	1.8	1.2
Turkmenistan	2.7	3.3	2.8	2.6	2.5	2.3	1.8	1.7	1.5	1.2	0.7	0.5
Algeria	2.6	2.7	2.4	2.7	3.0	1.5	2.0	0.8	1.5	2.3	0.7	3.0
Bulgaria	2.4	3.3	3.5	4.0	2.0	4.1	4.1	3.3	3.2	3.3	3.6	1.8
Sweden	2.3	2.0	2.2	2.4	2.3	2.1	2.4	2.4	1.7	2.2	2.1	2.0
Other	35.6											
World Total	607.0	605.9	628.7	633.3	560.3	574.7	589.7	586.1	587.7	593.6	613.4	585.4

Source: International Grains Council- hptt://en.wikipedia.org

Table 2: Top Ten Wheat Producers – 2007 (million metric ton)	
China	109
India	75.8
United States	56
Russia	49
France	33
Pakistan	23
Germany	21
Canada	20
Turkey	17
Argentina	16
World Total	**725**
Source: UN Food & Agriculture Organisation (FAO)	

With a projected population of 137.86 million people in 1997 (Ohiagu *et. al.*, 1987), wheat consumption in Nigeria was projected to reach 1.5 million metric tonnes, with domestic production lagging behind demands. Decades later, the prospect of meeting local wheat demands seem unlikely, particularly with the demise of most River Basin Development Projects (Olabanji *et al.*, 2004). To complicate issues, yields obtained on farmers' plots have often lagged behind world average.

Wheat cultivation in Nigeria up to 1985 was about 66, 000 tonnes (Anon, 1987), but rose to about 400, 000 to 600, 000 tonnes from a total land area of 215, 000 hectares between 1988 and 1989 with an average field yield of 2t ha^{-1} after ban was imposed on wheat importation. Average farm yield is still quite below what exist in the UK or the world average (see tables 3 and 4).

Wheat as an important industrial crop is the main raw material in feed mills, with bread, cake, biscuit, pasta, spaghetti, semovita, macaroni, containing reasonable amounts of wheat. The offal is used in compounding life stock feeds. After wheat harvest, the grain is separated from the stalks and chaff. The wheat stalks are used in a variety of applications: mulch, construction material, and as animal bedding. As food, wheat contributes more protein and calories to the diet than any other crop and world trade in wheat far exceeds the contributions of other grains put together.

Table 3: Average wheat yield per hectare in the United Kingdom 1998-2002

Year	Yield (T/ha)
1998	7.56
1999	8.05
2000	8.01
2001	7.08
2002	8.00
Average	7.74

Table 4: Average wheat yield per hectare and ranking in twenty six countries

Rank	Countries	Amount
1	United Kingdom:	7.78
2	Germany:	6.5
3	Egypt:	6.26
4	France:	6.23
5	Saudi Arabia:	4.71
6	Mexico:	4.53
7	China:	3.93
8	Poland:	3.4
9	United States:	2.97
10	India:	2.62
11	Hungary:	2.61
12	Argentina:	2.46
13	Pakistan:	2.37
13	Brazil:	2.37
15	Bulgaria:	2.27
16	Canada:	2.25
17	Bangladesh:	2.21
18	Iran:	2.08
19	South Africa:	2.06
20	Australia:	2.01
21	Turkey:	1.95
22	Morocco:	1.72
23	Ukraine:	1.47
24	Romania:	1.33
25	Algeria:	1.08
26	Kazakhstan:	0.97
	Total:	80.14
	Weighted average:	3.1

Source: http://www.nationmaster.com/gragh/

Plate 1: Utensil made of dry wheat branches for loaves of bread

If Nigeria must meet her demands for wheat, there is the need for improved methods of wheat cropping and large scale production with ultimate focus on expected yields (Oyewole *et al.*, 2005). The general consensus is that establishing adequate plant stand is a prerequisite for a successful crop. Eventual plant stands on farmers' plot is a product of many factors: seed rate, pests and diseases, seeding method etc.

Types of Wheat:

Wheats are classified based on species, commercial types, and growth habit. Based on these, there are sixteen species, two commercial types: bread (*Triticum aestivum*) and macaroni or Duran wheat (*Triticum durun*); and three growth habits (winter habit wheat, spring wheat and facultative wheat). Winter wheat lies dormant during a winter freeze.

Major cultivated species of wheat:

- Common wheat or Bread wheat (*T. aestivum*): A hexaploid species that is the most widely cultivated in the world.
- Durum (*T. durum*): The only tetraploid form of wheat widely used today, and the second most widely cultivated wheat.
- Einkorn (*T. monococcum*): A diploid species with wild and cultivated variants. Domesticated at the same time as emmer wheat, but never reached the same importance.
- Emmer (*T. dicoccum*): A tetraploid species, cultivated in ancient times but no longer in widespread use.
- Spelt (*T. spelta*): Another hexaploid species cultivated in limited quantities.

Harvested wheat grain that enters trade is classified according to grain properties for the purposes of the commodities market. Wheat buyers use the classifications to help determine which wheat to purchase as each class has special uses. Wheat producers determine which classes of wheat are the most profitable to cultivate with this system.

Classes used in the United States are:

- Durum: Very hard, translucent, light colored grain used to make semolina flour for pasta.
- Hard Red Spring: Hard, brownish, high protein wheat used for bread and hard baked goods. Bread Flour and high gluten flours are commonly made from hard red spring wheat. It is primarily traded at the Minneapolis Grain Exchange.
- Hard Red Winter: Hard, brownish, mellow high protein wheat used for bread, hard baked goods and as an adjunct in other flours to increase protein in pastry flour for pie crusts. Some brands of unbleached all-purpose flours are commonly made from hard red winter wheat alone. It is primarily traded by the Kansas City Board of Trade. One variety is known as "turkey red wheat", and was brought to Kansas by Mennonite immigrants from Russia.
- Soft Red Winter: Soft, low protein wheat used for cakes, pie crusts, biscuits, and muffins. Cake flour, pastry flour, and some self-rising flours with baking powder and salt added for example, are made from soft red winter wheat. It is primarily traded by the Chicago Board of Trade.
- Hard White: Hard, light colored, opaque, chalky, medium protein wheat planted in dry, temperate areas. Used for bread and brewing.
- Soft White: Soft, light colored, very low protein wheat grown in temperate moist areas. Used for pie crusts and pastry. Pastry flour, for example, is sometimes made from soft white winter wheat.

Red wheats may need bleaching therefore white wheats usually command higher prices than red wheats on the commodities market.

Ecology and Climatic Requirements:

The production of wheat in Nigeria is within latitude 10-14^{0} N and altitude of 240 – 360 m above sea level (Olugbemi, 1973) in the Sudan and Sahel savannah. Optimum air temperature for growth and the development of grain is 18 – 25 ^{0}C. High temperatures during developmental stages hasten growth and development, while shortening various developmental stages, making it impossible to achieve full yield potentials of the crop.

Production of wheat was initially confined to the Chad Basin and since temperate varieties were used, its cultivation was confined to the dry cold period between November and March, thus necessitating the use of

irrigation (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62).

Climate, as the average weather condition of a place for at least thirty-five years determines, not only what the farmer can plant, but major cultural practices and incidence of pests and diseases. Although wheat is known to have a broad adaptation (Olabanji *et al.*, 2004), it best thrive under temperate climate. High temperatures generally limit yield of wheat crop.

The major yield limiting factors of climate in the tropics are temperature and humidity. However, under very dry conditions, high soil temperature can negatively impact on yield, while humidity will favour incidence of pests and diseases (Olugbemi, 1990). Temperature requirement for wheat plays significant role in site selection for wheat cultivation, in addition to temperature requirement, wheat thrives best in well drained fertile loam sand to medium texture clay-loam and area of low night temperature.

Knowledge of stages is important to identify periods of higher risk, in terms of climate. For example, the meiosis stage is extremely susceptible to low temperatures (under 4 °C) or high temperatures (over 25 °C).

Sowing Date:

Sowing date significantly influence crop growth, development and yield. Although research to develop rain-fed wheat variety is on, wheat is basically a temperate crop, requiring temperate conditions which only exist in the Sudan and Sahel savannah during the dry cold season of November/ December. Thus the crop is usually sown between November/December to be harvested March/April. The optimum time for seed sowing is mid November. Sowing earlier or later than Mid November will affect yield in wheat crop (Falaki, 1994). Delay in seed sowing has been observed to expose the crop to high temperatures, aphid and stem borer attacks (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62).

Seed Treatment:

Establishing an adequate crop stand is a prerequisite for a successful wheat crop, thus seed treatment is a vital process in achieving this. Seed treatment will ensure high percentage germination, good crop stand; and all things being equal, good crop yield. Seed treatment with appropriate pesticide will enhance better seed germination by preventing or reducing the incidence of pests. Apron Star 50DS applied

at the rate of 10g of Apron Star for 4 – 6 kg of seeds is the common practice.

Land Preparation:

Land preparation requirement for wheat depends on the cropping history of the land to be used. As a dry season crop, land preparation usually begins early November after the harvest of the last rain-fed crops. It is however, not uncommon to have land preparation done before the end of October. The current crop under cultivation prior to incorporating the wheat crop into the cropping system, will determine when to begin the process of land preparation. The Site should be ploughed and harrowed to a good tilt. Since wheat crops are grown under irrigation in Nigeria, there is usually no need for ridging as irrigation is by gravity. Water movement by gravitational pull requires achieving a level of slope. Levelling the field to a slope of 0.25 – 0.30% to a drain located at the tail of the field will ensure free water movement. Sunken beds are prepared in such a way to allow for free water movement.

Seed Sowing: Broadcasting, Drilling and Dibbling:

Seed sowing is an important operation requiring, utmost care. Establishment of adequate crop stand is a prerequisite for a successful crop and this depends on seedling emergence, which may be affected by sowing method employed by farmers. Sowing method employed by farmers is basically determined by the available technology rather than by the expected yield. Basically wheat crop can be drilled, dibbled or broadcast (Chapman and Carter, 1976; Graham and Ellis, 1980; Jacquot and Courtois, 1993; Oyewole, 1999; Oyewole *et al*., 2001; Oyewole *et al*., 2005).

In early American history, wheat was sown broadcast (Kipps, 1983), however, broadcasting has been observed to reduce plant establishment as seeds are said to be lost to pests and unfavourable weather conditions. Consequently, high seed rates have been recommended when seeds are broadcast in order to compensate for seed loss. Presently in America almost all wheat is drilled. The main reason given for drilling wheat was better germination, which resulted in higher stands compared to broadcasting (Kipps, 1983).

Though better crop establishment and crop yield has been reported when wheat is drilled compared to other sowing methods, however, wheat drilling is an expensive technology in the form of labour requirements for drilling or machinery employed in seed drilling. Thus, seed broadcasting or dibbling is prevalent on farmers' plots.

Broadcasting, it was observed, even when followed by harrowing or raking does not bring seed in perfect contact with the soil for adequate water uptake (kipps, 1983; Oyewole, 1999; Oyewole *et al.*, 2001; Oyewole *et al.*, 2005).

In Nigeria, sowing methods employed by farmers vary considerably from area to area. In Kadawa, Kano State, the vast majority of the farmers broadcast their seeds, while farmers in Ringim, Jakarade and Hedjia dibbled either on the ridge or on the flat.

Spacing

Spacing is only relevant when wheat crop is drilled or dibbled, but not in broadcast wheat plots, which involves even spreading of seeds. When drilled, spacing of 25 - 30 cm is usually observed between rows. In dibbled stands, seeds are dibbled at 25 - 30 x 25 - 30 cm apart.

Seed Rate:

Seed rate of 120-140 $kgha^{-1}$ is recommended when sowing wheat. Higher seed rate is encouraged when broadcasting as against drilling or dibbling (Oyewole, *et al.*, 2001). When seeds are broadcast, it is important to rake in the seeds to reduce exposure to ant predation (Oyewole *et al.*, 2001; Oyewole *et al.*, 2005)

Fertilizer Application:

Wheat responds well to NPK fertilizer application. Application of 100 - 120 $kgNha^{-1}$ and 40 - 60 Kg P_2O_5 ha^{-1} and 40 – 60 kg K_2O ha^{-1} has been recommended. P and K should be applied prior to seed sowing and incorporated into the soil. Except in sandy soils, N can be applied prior to seed sowing as single dose. However, for highly porous sandy soils N should be applied in split doses, first at planting, then three or four weeks after seed sowing (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62).

Current recommendations often indicate that the second application of nitrogen be done when the ear (not visible at this stage) is about 1 cm in size (Z31 on Zadoks scale). Several systems exist to identify crop stages, with the Feekes and Zadoks scales being the most widely used. Each scale is a standard system which describes successive stages reached by the crop during the agricultural season. Crop management decisions require the knowledge of stage of development of the crop. In particular, spring fertilizer applications, herbicides, fungicides, growth regulators are typically applied at specific stages of plant development (Wikipedia, the free encyclopedia).

Weed Control and Pest Control:

Cereals, including wheat crop, are generally most susceptible to competition from weeds in the first few weeks of growth. Competition can be minimized by sowing into clean seedbed; at or immediately after soil preparation. The advantage of row sowing can not be over stressed, for they allow weeding to be carried out. Broadcasting wheat seeds during seed sowing hamper such operation. If herbicide is to be employed in weed control, knowledge of the predominant weed on the farm is necessary. The time of wheat cultivation does not coincide with period of optimum weed interference. However, as temperature warm up in February, weeds will begin to emerge. For this reason, manual hoe weeding, or post emergence application of chlorotoluron at 2.0kg aiha^{-1} or application of bentazone at 1.5kg aiha^{-1} at four weeks after sowing is recommended (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62). Serious pest incidences have not been reported in wheat crops in Nigeria (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62).

Plate 2: Wheat seeds

However, delay in sowing can lead to aphid and stem borer infestations. There are also incidences of rodent and bird attacks (Abate, 1993; Ajayi, 1983; Ashley, 1993; Oyewole *et al.*, 2001; Olabanji *et al.*, 2004; Oyewole *et al.*, 2005). There are also threats from insect pests: crickets, harvester ants, termites, etc. Loses due to pests and diseases is reported to range between 30 – 35% (Olabanji *et al.*, 2004).

The control of wheat pests have been achieved through cultural practices (Oyewole, 1999; Falaki and Uvah, 1994), use of resistance varieties and the use of pesticides (Oyewole, 1999).

Farmers will benefit from knowing when the flag leaf (last leaf) appears as this leaf represents about 75% of photosynthesis reactions during the grain-filling period and as such should be preserved from disease or insect attacks to ensure a good yield.

Water Management:

Wheat will grow in areas with rainfall as low as 15 inches (38.1 cm). However, wheat fields in these arid areas will not a have a crop for a full year before the wheat. Commercial wheat production in Nigeria is entirely dependence on irrigation. Effort to grow rain fed wheat is still rudimentary. Wheat crop grown on sandy soils should be irrigated

frequently than those cultivated on clayish soils. For sandy loam, irrigation intervals of 5-7 days until booting state is recommended and subsequent irrigation should be at 7 days intervals. In medium to heavy soils 7 – 8 days irrigation interval is recommended. Water stress at flowering will negatively affect yield by reducing grain number and weight. Irrigation should be terminated two weeks to crop harvest (National Agricultural Extension and Research Liaison Services, ABU, Extension Bulletin No. 62). In situations where wind is a threat, causing breakages, or where variety grown is prone to lodge, there may be the need to terminate irrigation early. In either case, fall panicles tend to rot on contact with water.

Plate 3a: Wheat Panicle
Plate 3b: Matured Wheat Crop
Plate 3c: Wheat plot not ready for harvest

Harvesting, Processing and Utilization:

When wheat is ready for harvest, the heads of the grain start to bend the stalks with the weight of the kernels. This, in combination with the golden colour, indicates that it is time to harvest the wheat (10 – 12 % moisture level). Wheat which is sown in mid November is usually ready for harvest in April. Wheat normally requires between 110 and 130 days between planting and harvest, depending upon climate, seed type, and soil conditions. After harvest, the field is cleared and prepared for planting again. Farmers using good rotation practices do not plant wheat in sequential years, although they may return to the field later.

Although wheat can be combined harvested, in Nigeria, wheat harvest is basically accomplished with the use of sickle. Where sickles are used, the harvest is tie into shelves for threshing on hard platform. The crop is then winnowed to separate the chaff from the grain. The grain can be processed and used or stored until required. Once the kernels have been separated, they can be ground into flour.

There are many classifications for wheat flour, depending on what part of the seed is used and the hardness of the endosperm. Wheat kernels

have three parts: the small germ, the large endosperm, and the rough outer casing known as the bran. Hard wheat is suitable for making pasta and bread, and soft wheat is used for other wheat products that do not require high gluten content. If flour is made solely from the endosperm, it is known as white flour. If the germ is ground as well, the product is called germ flour. Flour that uses the whole kernel is called whole wheat. When making flour that doesn't use the whole kernel, the bran and germ are processed and sold separately.

Processing: Traditional method:

Harvesting →Threshing →Winnowing → De-stoning (sorting to remove stones and foreign materials →Cleaning in water to remove adhering soils → Draining →De-hulling in mortar →Winnowing to remove bran →Washing de-hull grains →Sun-drying →Milling

Utilization:

100 grams of hard red winter wheat contain about 12.6 grams of protein, 1.5 grams of total fat, 71 grams of carbohydrate (by difference), 12.2 grams of dietary fiber, and 3.2 mg of iron (17% of the daily requirement); the same weight of hard red spring wheat contains about 15.4 grams of protein, 1.9 grams of total fat, 68 grams of carbohydrate (by difference), 12.2 grams of dietary fiber, and 3.6 mg of iron (20% of the daily requirement).

Much of the carbohydrate fraction of wheat is starch. Wheat starch is an important commercial product of wheat, but second in economic value to wheat gluten. The principal parts of wheat flour are gluten and starch. These can be separated in a kind of home experiment, by mixing flour and water to form a small ball of dough, and kneading it gently while rinsing it in a bowl of water. The starch falls out of the dough and sinks to the bottom of the bowl, leaving behind a ball of gluten.

Wheat grains have been used by man for centuries. Various dishes have evolved over time ((Olabanji *et al.*, 2004). About 2/3 of the wheat cultivated world wide is used as food, while the remainder is used as feed and as seed for sowing (about 7% of cultivated wheat). Wheat starches are used industrially for paper sizing, laundry starch, glucose and glucose syrup production, manufacture of board, adhesives, glasses, inert carriers for chemicals, production of alcohol, plastics, vanishes, soaps, rubber and cosmetics (Olabanji *et al.*, 2004).

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Fig 4: Wheat spikelet with the three anthers sticking out

Plate 5: Wheat ear

Face view Side view

Plate: Wheat at the anthesis stage

Acknowledgements
Wikipedia.org for **Plate**: 1, 4, 5 and 6
http://www. google.com for **Plate** 2, 3a,band c